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Nuclear Disintegration Schemes and the Coincidence Method*

Nature and geometry of counters for measuring beta-gamma, gamma-gamma, and beta-beta coincidences are discussed, together with methods for obtaining data for decay schemes

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THE IMPORTANCE of the use of coincidence counting in experiments concerned with cosmic rays and nuclear physics has long been recognized. The method is particularly applicable to the determination of disintegration schemes of radioactive nuclei. This paper will not attempt to cover all aspects of the coincidence method but will restrict itself to that part which is related to the working out of disintegration schemes.

Several other papers have been published on this subject (*1*). It is the purpose of the writers to review the general technique and to give in some detail the methods which have been employed by them in the past year. Thus far, they have investigated about thirty pile-produced isotopes using the methods to be described.

The particular form of coincidence counting under discussion had its inception at Heidelberg in 1935 where Bothe and von Baeyer performed the early experiments on Ra(B + C). Since that time many investigators and groups of investigators have recognized the sensitivity of the approach which they initiated. After these first experiments, coincidence investigations of radioactive nuclei were carried out by Norling in Sweden, Feather and Dunworth at the Cavendish Laboratory, Mitchell and co-workers at Indiana University, Deutsch and collaborators at the Massachusetts Institute of Technology, and Scherrer and collaborators in Switzerland. At the present time the number of workers using the method in this country is too great for detailed enumeration.

The Radioactive Transformation

The disintegration of a radioactive nucleus by beta decay is now fairly well understood. It is usually considered that the initial nucleus emits a beta particle, transforming itself into the residual or final nucleus. The residual nucleus may be in its ground state or in an excited state, in which case it will decay to the ground state with the emission of one or more gamma rays. Radioactive scandium-46 provides a good example. The disintegration scheme (*2*) for Sc^{46} is shown in Fig. 1. The diagram shows that the beta ray emitted by Sc^{46} is followed by two gamma rays in cascade, emitted when the Ti^{46} residual nucleus de-excites. Since the beta ray is followed by gamma radiation, the condition for beta-gamma coincidences exists. Gamma-gamma coincidences will also be present, since the two gamma rays

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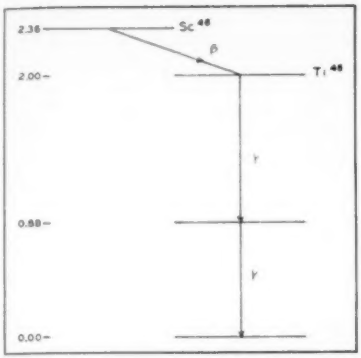

FIG. 1. Disintegration scheme for Sc^{46}

are in cascade. Among the heavy nuclei, it often happens that the gamma radiation is to some extent converted; that is, an extra-nuclear electron is ejected as an alternative to gamma emission. In this instance, the beta ray of the radioactive transition is followed by the conversion electron so so that it is possible to measure beta-beta coincidences.

Apparatus and General Procedure

It is necessary to measure the above discussed beta-gamma, gamma-gamma, and beta-beta coincidences when studying the breakup of radioactive nuclei. Each of these three types of measurements requires its own particular variety of counters and geometry. In Fig. 2 are shown two thin-walled gamma-ray counters arranged to measure gamma-gamma coincidences. The cathodes of the gamma-ray counters are aquadag coatings on glass, having a length of 5 cm and a diameter of 1.5 cm. The surface density of the nonex glass walls of the counters is 25 mg per cm^2. The diameter of the anode wires of tungsten is 0.0075 cm. In Fig. 2, the gamma-ray counters are shielded by two aluminum blocks, indicated by the cross-sectioned areas, sufficiently thick to stop the primary beta rays

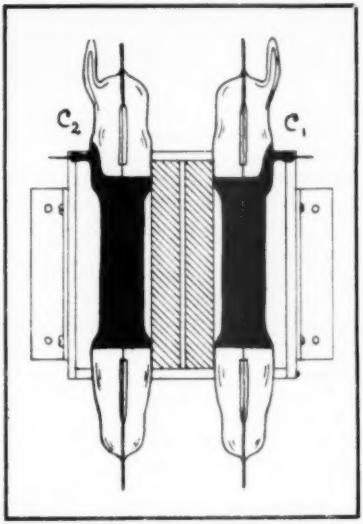

FIG. 2. Coincidence counting arrangement for measuring gamma-gamma coincidences

emitted by the source which is placed in the gap between the blocks.

For counting beta-gamma coincidences, the block in front of counter C_1 is removed so that it counts both beta rays and gamma rays. The beta-gamma coincidence rate must be corrected for the presence of the previously measured gamma-gamma coincidences. The single counting rate in the beta-ray counter must also be corrected for the presence of gamma rays. It is to be remembered that the coincidences are recorded by a double coincidence circuit having a finite resolving time, so that a certain number of "accidental" coincidences are also recorded. For the purpose of correction, the accidentals per minute can be calculated by the equation

$$A = N_1 N_2 (K\tau)$$

where N_1 and N_2 are the single counts per minute recorded in either counter; τ is the coincidence resolving time, and

K is a constant, very often taken to be two. The product $K\tau$ is measured experimentally at the outset of the coincidence experiment by separating the two counters, shielding them from each other, and using a beta-ray source in front of either counter to give statistical coincidences. It is evident that any coincidence experiment must be corrected for these accidental coincidences.

For a fixed geometry, the beta-gamma coincidences per beta ray recorded in the beta-ray counter and the gamma-gamma coincidences per gamma ray recorded in either of the gamma-ray counters are not without significance. It can be shown that if the beta rays are followed by n gamma rays in cascade.

$$N_{\beta\gamma}/N_\beta = \sum_1^n \epsilon_j \qquad (1)$$

where $N_{\beta\gamma}/N_\beta$ denotes beta-gamma coincidences per beta ray and ϵ_j is the quantum efficiency (including solid angle) of the gamma-ray counter for the j^{th} gamma ray. This efficiency has been studied for cathode materials of many varieties, and as a general rule, increases with the gamma-ray energy. Again assuming that n gamma rays are in cascade,

$$\frac{N_{\gamma\gamma}}{N_\gamma} = \frac{\sum_1^n \epsilon_i\epsilon_j}{\sum_1^n \epsilon_j}, \qquad i \neq j \qquad (2)$$

where $N_{\gamma\gamma}/N_\gamma$ denotes gamma-gamma coincidences per gamma ray recorded in either of the symmetrically placed, identical gamma-ray counters. For Sc^{46}, equations 1 and 2 reduce to

$$N_{\beta\gamma}/N_\beta = \epsilon_{1.12} + \epsilon_{0.88} \qquad (3)$$

and

$$\frac{N_{\gamma\gamma}}{N_\gamma} = \frac{2\epsilon_{1.12}\epsilon_{0.88}}{\epsilon_{1.12} + \epsilon_{0.88}} \qquad (4)$$

It is evident that, from equations 3 and 4, the net efficiency of the gamma-ray counter for quantum energies of 0.88 and 1.12 Mev can be obtained.

The writers have employed only gamma-ray counters made of "low Z" materials such as the glass-aquadag counter shielded by an aluminum block. The energy-efficiency curve for an aluminum counter is very nearly a linear relation.* In this case, equation 1 becomes

$$N_{\beta\gamma}/N_\beta = \sum_1^n \epsilon_j = B\sum_1^n (h\nu)_j,$$

$$B = \text{constant} \qquad (5)$$

In other words, the beta-gamma coincidence rate is directly proportional to the total amount of gamma-ray energy which follows the beta rays. The application of this convenient principle is not necessarily limited to the case of the beta ray followed by n gamma rays in cascade. If the beta-ray spectrum is simple, and if the residual nucleus de-excites to the ground state with the emission of gamma rays following several different modes, the beta-gamma coincidence rate will again be proportional to the total de-excitation energy, regardless of the number of modes.

This linear dependence of the beta-gamma coincidence rate upon the total de-excitation energy has several appealing aspects in so far as calibration of a "low Z" gamma-ray counter is concerned. To calibrate a gamma-ray counter for a fixed geometry, the writers have simply measured the beta-gamma coincidence rate of Sc^{46}. A line through this point and the origin then serves as a calibration curve for the counter, as shown in Fig. 3. The use of "high Z" gamma-ray counter cathodes of brass, lead, or gold leads to

* See, for example, W. A. Fowler, C. C. Lauritsen and T. Lauritsen, *Phys. Rev.* **73**, 181 (1948).

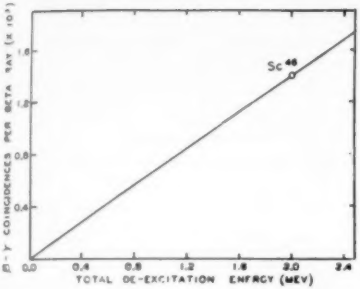

FIG. 3. Calibration curve for "low Z" counter

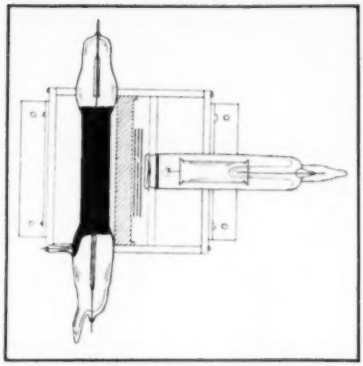

FIG. 4. Coincidence counting arrangement for measuring β-γ coincidences

a calibration curve which is usually more complicated in form than a straight line. If during the use of a gamma-ray counter of "low Z" materials, the counter is broken or becomes unserviceable for other reasons, the counter can be replaced and the new one recalibrated quickly by the Sc^{46} point corresponding to 2 Mev of de-excitation energy.

It has been argued that since the quantum efficiency of a counter should rise with increasing electron density of the cathode material, only "high Z" counters should be used. The writers feel that the low efficiency of the "low Z" counters is offset by the advantage of rapid calibration by taking the beta-gamma coincidence rate for a single isotope such as Sc^{46}. A survey of the many coincidence rates for various isotopes which have been published in the open literature shows that these do not exceed those obtained by the authors by more than a factor of two. With a source of Sc^{46} located 1.0 cm from the wall of an aquadag gamma-ray counter having the dimensions given earlier in the paper, the beta-gamma coincidence rate was 1.4×10^{-3} coincidence per beta ray with 2 gm per cm^2 of aluminum shielding the gamma-ray counter. When the shielding material was reduced to 0.2 gm per cm^2 of aluminum with the source at the same distance from the counter, the beta-gamma coincidence rate was 3×10^{-3} coincidence per beta ray. The writers have concluded that the thin wall (25 mg per cm^2) of the glass-aquadag gamma-ray counter allows recoil electrons produced over a large area of the aluminum shield to enter the counter and give an apparent increase in solid angle which would not occur were the cathode thick and made of a heavy element.

Observation of beta-gamma coincidences per recorded beta ray as a function of aluminum absorber thickness inserted before the beta-ray counter yields interesting information which will be discussed later in the paper. In this method, one of the two aquadag counters of Fig. 2 can be used as the beta-ray counter, and aluminum foils can be placed in front of it. However, in the case of some isotopes, the beta rays are so soft as to be heavily absorbed in the wall of the glass-aquadag counter. Accordingly, to measure the beta-gamma coincidence rate as a function of absorber thickness in front of the beta-ray counter, the counter arrangement of Fig. 4 has been employed. The gamma-ray counter remains unchanged, but the beta-ray

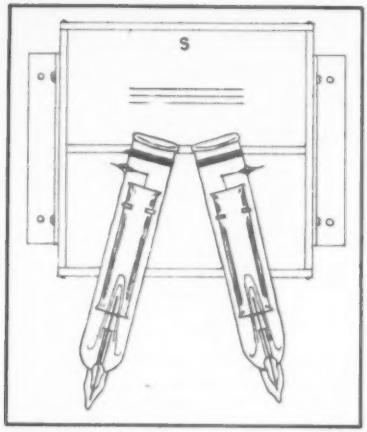

FIG. 5. Coincidence counting arrangement for measuring β-β coincidences

counter is now a thin-window "bubble" counter. The surface density of the bubble is 2.5 mg per cm². Two sizes of counters have been used: one having a bubble diameter of 1 cm and a copper cathode length of 3 cm, the other having a bubble diameter of 1.5 cm and a correspondingly larger and longer cathode.

For measuring beta-beta coincidences, two beta-ray counters are placed side by side, as shown in Fig. 5, with the source at *S*. The beta-beta coincidences per thousand beta rays are observed as a function of the thickness of the aluminum absorber placed in front of both of the counters. Suppose that the nuclear beta rays are followed by a single gamma ray which is partially converted. At zero absorber thickness,

$$N_\beta = N(1 + \alpha)\left(\frac{\sigma}{4\pi}\right) \qquad (7)$$

$$N_{\beta\beta} = 2N\left(\frac{\sigma}{4\pi}\right)^2 \alpha \qquad (8)$$

so that

$$\frac{N_{\beta\beta}}{N_\beta} = \frac{2\left(\frac{\sigma}{4\pi}\right)\alpha}{1 + \alpha} \qquad (9)$$

where

N = total number of disintegrations per minute

N_β = number of beta particles recorded per minute in the beta-ray counter

$N_{\beta\beta}$ = number of beta-beta coincidences per minute

σ = solid angle subtended at the source by the beta-ray counter

α = conversion coefficient

Also,

$$N_{\beta\gamma} = N(1 - \alpha)\left(\frac{\sigma}{4\pi}\right)^2 \epsilon_\gamma \qquad (10)$$

$$N_\gamma = N(1 - \alpha)\left(\frac{\sigma}{4\pi}\right)\epsilon_\gamma \qquad (11)$$

$$\frac{N_{\beta\gamma}}{N_\gamma} = \frac{\sigma}{4\pi} \qquad (12)$$

$$\left(\frac{N_{\beta\beta}/N_\beta}{N_{\beta\gamma}/N_\gamma}\right) = \frac{2\alpha}{1 + \alpha} \qquad (13)$$

where

$N_{\beta\gamma}$ = number of beta-gamma coincidences per minute

N_γ = number of gamma-ray counts recorded in either of the identical beta-ray counters

ϵ_γ = net efficiency of either of the beta-ray counters for the gamma radiation

From equation 13, it is clear that the conversion coefficient can be calculated. As previously remarked, the equations leading to α actually hold only at zero absorber thickness. Since the beta-ray counter windows have a finite surface density, it is necessary to make a semi-logarithmic plot of the coincidence rates as a function of absorber thickness and extrapolate to zero absorber thickness. The extrapolated values are used to calculate α.

When the beta ray is followed by several gamma rays, one of which is converted, equations more complicated, but similar in form to those above, then apply. It is evident that the beta-beta coincidences must be corrected for the presence of beta-gamma, gamma-gamma, and accidental coincidences.

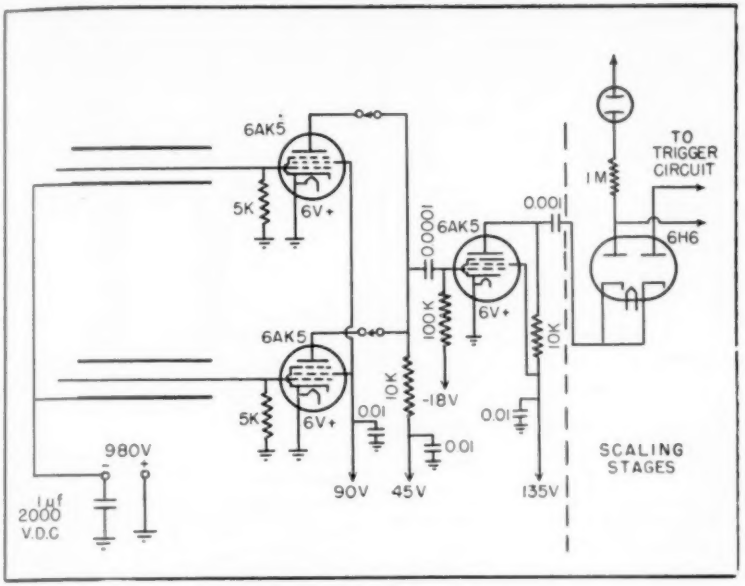

FIG. 6. Fast coincidence circuit

A diagram of the coincidence circuit is given in Fig. 6. This simple circuit has been found to be very reliable and has been used for measuring beta-gamma, gamma-gamma, and beta-beta coincidences as well as for carrying out coincidence absorption measurements, which will be described later. With the circuit as shown, and with certain carefully chosen counters, resolving times as low as 0.035 microsecond without genuine coincidence loss have been reached. The writers have previously published (*3*) an account of experiments wherein beta rays are passed through two counters in coincidence, and the genuine coincidence rate is measured as a function of the resolving time. With this particular circuit, the resolving time has been found to be as much a function of the rise time of the counter pulses as of the circuit parameters. In the experience of the writers, the argon-ethyl ether mixture has provided the shortest rise times and dead times. The absence of any significant time lags for the gas mixture and counter geometries employed makes possible the use of the short resolving time previously mentioned. For input resistors of 20K and a bias voltage of −19.5 volts, the resolving time is of the order of one microsecond.

Supplementary Experiments

In the previous section the chief concern was with the coincidence rates and how they were measured. In the construction of a level diagram, it is necessary to know as much as possible about the energies of the beta rays and gamma rays. A rapid and convenient method for measuring the beta-ray energy is that of absorption in aluminum before a single Geiger-Müller counter. With a counter similar to the

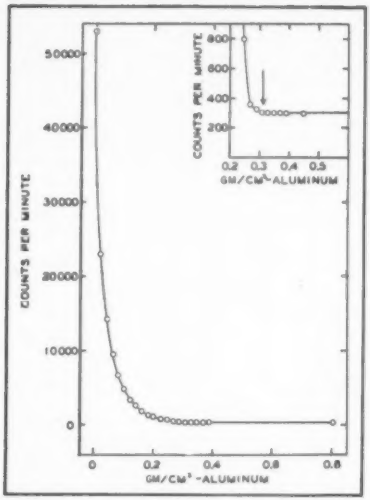

FIG. 7. Absorption in aluminum of the beta rays of Au^{198}

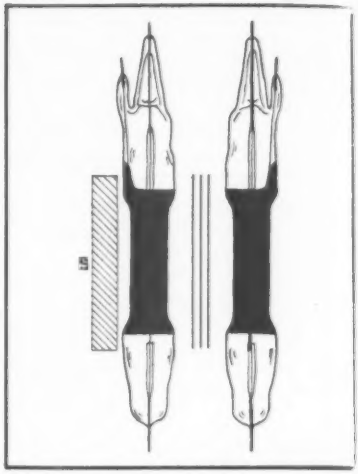

FIG. 8. Counter arrangement for coincidence absorption experiments

"bubble" counters shown in Figs. 4 and 5, the absorption curve in Fig. 7 was obtained for the beta rays of gold ($A = 198$). The endpoint of the curve corresponds to a maximum beta-ray energy of 0.87 Mev as determined by Feather's equation (*4*) which is

$$R = 0.54\,E - 0.16 \qquad (14)$$

where R is the range in gm/cm² and E is the maximum energy in Mev of the beta particles. Using Feather analysis (*4*), which has been discussed in considerable detail in this journal by Glendenin (*5*), a somewhat higher value of 0.96 Mev is calculated. On occasion, when a semi-logarithmic plot is made of the absorption data, evidence for the presence of more than one beta spectrum can be deduced.

Any one of several absorption techniques can be employed for the determination of gamma-ray energies. The most common method is lead absorption wherein the absorption coefficient gives a measure of the quantum energy.

The writers have favored coincidence absorption in aluminum of the secondary electrons produced by the gamma rays in a thick aluminum block. The experimental arrangement is shown in Fig. 8. The source is placed at S behind the thick aluminum radiator. The recoil electrons ejected by the gamma rays traverse both of the thin-walled counters to give genuine coincidences which are absorbed out by placing aluminum foils between the two counters. The counters are of the same thin-walled aquadag type as shown in Fig. 2.

The coincidence absorption experiments have been carried out using the simple coincidence circuit of Fig. 6. A resolving time of 0.10 microsecond is particularly convenient for these measurements, since the accidental background is negligible for reasonable single counting rates in either of the two counters. The coincidence absorption curve for the recoil electrons of the gamma rays emitted by the 72-day isomer of Ti^{51} is given in Fig. 9. It is

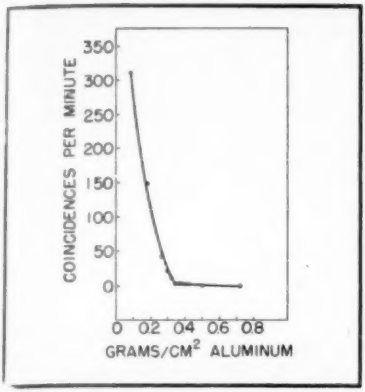

FIG. 9. Coincidence absorption curve for the gamma rays of Ti^{51}

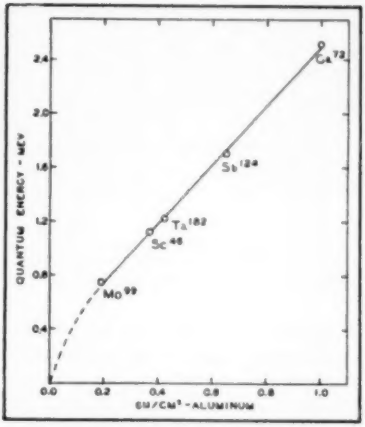

FIG. 10. Calibration curve for the coincidence absorption counting arrangement

clear from the figure that the coincidence rate drops to a sharply defined endpoint. In order to calibrate the counter arrangement used in the coincidence absorption measurements, the maximum gamma-ray energies were determined for several isotopes which have been thoroughly studied by spectrometric methods. These accurate values are plotted against the aluminum absorber thickness in grams per square centimeter to give the endpoint in the coincidence absorption measurements. These data are shown in Fig. 10. This serves as a calibration curve, giving the quantum energy when the endpoint of the recoil electrons is known. When the geometry is changed, it is necessary to construct a new calibration curve.

For most isotopes, a coincidence absorption curve gives only the maximum energy of the gamma rays with any accuracy. There are a few notable exceptions. The coincidence absorption curve for La^{140} is given in Fig. 11. The first break in the curve occurs at 0.60 gm/cm², corresponding, according to the calibration curve of Fig. 10, to a quantum energy of 1.60 Mev. Upon expanding the ordinate in the vicinity of 1.0 gm/cm², it is apparent that a second gamma ray is present, having a recoil electron endpoint at 0.95 gm/cm² corresponding to a quantum energy of 2.38 Mev.

Interpretation of Coincidence Curves

The beta-gamma coincidence rate for Sb^{124} is shown in Fig. 12. This curve was obtained by placing thin aluminum foils in front of the beta-ray counter and observing the beta-gamma coincidence rate as a function of the absorber thickness. The beta-gamma coinci-

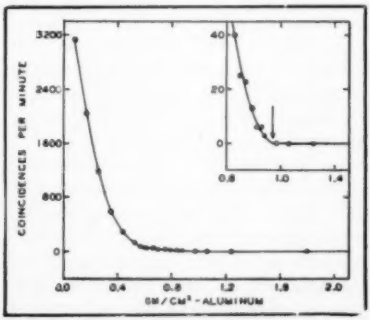

FIG. 11. Coincidence absorption curve for the gamma rays of La^{140}

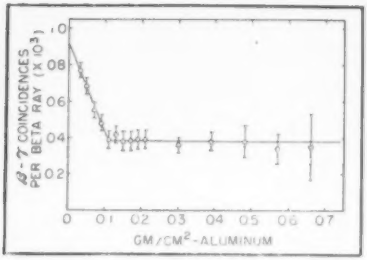

FIG. 12. Beta-gamma coincidence rate for Sb^{124}

dence rate decreases from an extrapolated value of 0.92×10^{-3} coincidence per beta ray at zero absorber thickness to 0.38×10^{-3} coincidence per beta ray at 0.11 gm/cm², corresponding to a beta-ray energy of about 0.4 Mev (*5*). Thus, the coincidence rate has shown that at least two beta-ray groups are present, the lower energy group being coupled with more gamma-ray energy than the higher energy group.

The shape of the curve in Fig. 12 can be clearly understood when it is remembered that each of the two beta-ray groups is a continuum, the one of lower maximum energy being absorbed out more rapidly. As more and more absorber is placed in front of the beta-ray counter, the high energy group becomes increasingly predominant. Since the low energy group is coupled with more gamma rays, the beta-gamma coincidences per beta ray recorded in the beta-ray counter decrease as the softer beta-ray group is cut out by the increasing absorber thickness. Beta-ray absorption curves give a beta-ray endpoint at about 2.1 Mev, and coincidence absorption indicates a maximum gamma-ray energy of 1.7 Mev. The beta-gamma coincidence rate of 0.38×10^{-3} coincidence per beta ray at large values of absorber thickness shows, according to calibration of the beta-gamma coincidence counting set by Sc^{46} (see Fig. 3), that the high energy beta-ray group is

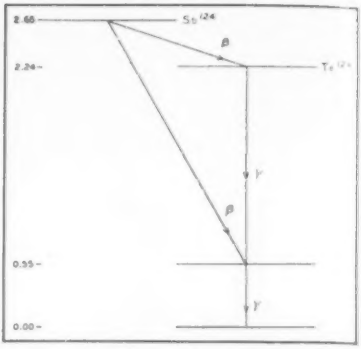

FIG. 13. An approximate disintegration scheme for Sb^{124}

coupled with about 0.55 Mev of gamma-ray energy. A gamma-gamma coincidence rate of $(0.59 \pm 0.02) \times 10^{-3}$ coincidence per gamma ray was also measured, indicating cascade emission of gamma rays.

The above quoted absorption and coincidence data can be combined to give the level diagram of Fig. 13. This is actually only a good first approximation to the complete disintegration scheme of Sb^{124}. Cook and Langer (*6*) and Kern, Zaffarano and Mitchell (*7*) have shown that the disintegration of Sb^{124} involves many gamma rays and beta-ray spectra in addition to those of Fig. 13. The spectrometric values of the beta- and gamma-ray energies as obtained by those authors are much more accurate than those obtained by the absorption and coincidence measurements alone. They are more meaningful, however, when supplemented by coincidence measurements, as was done by Jurney and Mitchell (*8*).

Another interesting beta-gamma coincidence curve is that of As^{76}, shown in Fig. 14. The coincidence rate drops to zero at 1.0 gm/cm², corresponding to 2.16 Mev, showing that beyond this point there are beta rays which are non-coincident with any gamma rays. This is interpreted as meaning that the

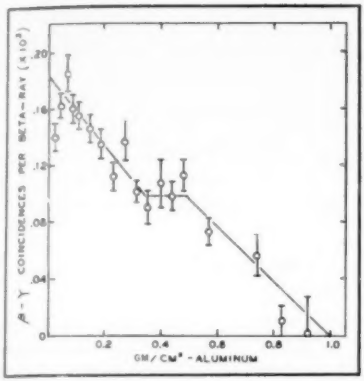

FIG. 14. Beta-gamma coincidence rate for As^{76}

beta-ray spectrum of highest maximum energy leads to the ground state of the Se^{76} residual nucleus. The endpoint of the spectrum of greatest maximum energy has been reported to be between 2.7 and 3.2 Mev, depending on the method of measurement. The breaks in the curve at 1.0 gm/cm² and 0.35 gm/cm² are thought to be the endpoints of two other spectra which are coupled with gamma rays. This curve was, of course, corrected for the presence of gamma-gamma coincidences and accidentals.

The beta-gamma coincidence rate for Au^{198} is shown in Fig. 15. It is clearly constant, independent of the beta-ray energy, suggesting that only one beta-ray group is present. In other words, the spectrum is simple. The method described in this paper of observing beta-gamma coincidences as a function of aluminum absorber thickness in front of the beta-ray counter is an integral method and so does not have high resolution. It follows that any spectra having an intensity only a few percent of the principal component would be difficult to detect. This fact has been born out by experiments (*9*) of the writers in connection with the complex beta-ray emitter, lanthanum-140.

A typical beta-beta coincidence curve is shown in Fig. 16, where the beta-beta coincidence rate of Ir^{192} is plotted as a function of aluminum absorber thickness placed in front of both of the beta-ray counters. Extrapolation of the coincidence rates to zero absorber thickness gives the total conversion coefficient.

Wiedenbeck and Chu (*10*) have introduced a modification wherein absorbers are placed in front of only one of the two beta-ray counters. From the shape of such beta-beta coincidence curves, certain conclusions can be drawn with regard to the relative values of the energies of the nuclear beta rays and the conversion electrons.

Metastable States

It has been known for some time that gamma radiation emitted in the de-excitation of some residual nuclei is delayed. The half-life of such delays has thus far been shown to vary from a few tenths of a microsecond to a period of years.

DeBenedetti and McGowan (*11*, *12*) have measured short-lived metastable states of half-lives 22 microseconds and 0.6 microsecond, respectively, in the disintegration of Hf^{181} and W^{187}. Their

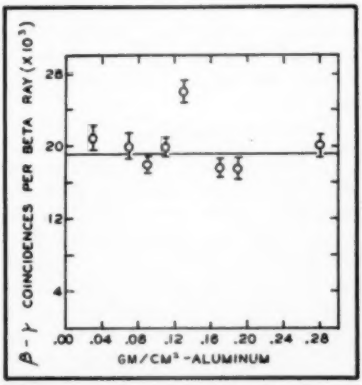

FIG. 15. Beta-gamma coincidence rate for Au^{198}

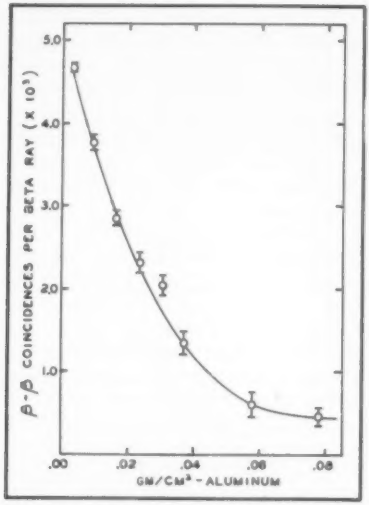

FIG. 16. Beta-beta coincidences in the disintegration of Ir^{192}

procedure has been to measure the beta-gamma coincidence rate as a function of the delay in one channel of a coincidence analyzer. The writers have succeeded in surveying metastable states over the interval $0.035 < \tau < 20$, τ in microseconds, by varying the resolving time of the coincidence circuit shown in Fig. 6. When the resolving time is just equal to the half-life of the metastable state, the genuine beta-gamma coincidence rate should be only half as great as at an infinite resolving time.

Conclusion

In recent years, variations on the coincidence techniques described in the preceding pages have provided improved resolution. With the advent of high-resolution beta- and gamma-ray spectrometers, the idea of "coincidence spectroscopy" has developed (*13*). The gamma-ray counter is located in the vicinity of the radioactive source in the spectrometer. The beta-ray counter of the spectrometer records beta rays lying in a given momentum interval which are coincident with some of the gamma rays recorded in the gamma-ray counter. A plot of beta-gamma coincidences per thousand beta rays recorded in each momentum interval gives a differential coincidence curve which obviously has higher resolution than the procedures previously described in this paper.

APPENDIX: Preparation of Sources

The radioactive materials were usually powdered and mixed with collodion. A drop of the mixture was then spread upon a thin sheet of aluminum or upon the gummed side of a piece of Scotch tape. The source thus prepared was usually attached to the aluminum block shielding the gamma-ray counter. In some cases, the powder was simply mashed into the Scotch tape. The sources were usually weighed on a micro-balance. The surface density varied, depending on the isotope, from a few milligrams per square centimeter to a few hundred micrograms per square centimeter.

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Review of Conventions in Radiotracer Studies

An analysis of expressions found in the literature with suggestions for conventions for future use*

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SINCE THE CLASSICAL PAPER of Chiewitz and Hevesy in 1935 (*155*), a large number of biological papers have appeared dealing with the use of radioactive tracers. The investigations have been carried out in many laboratories and the results were expressed in a variety of ways that seemed most reasonable to the investigators at the time. The many expressions which have appeared in the literature make difficult a comparison of results presented in different papers. The confusion has been increased by the naming of expressions, often using the same name for different expressions and, conversely, using several names for a single expression.

Development of more elaborate techniques and increased understanding of metabolic processes have rendered inadequate many of the earlier expressions. With the increased availability and the more widespread application of radioactive tracers to biological work, it seems timely to suggest conventions for the future reporting of data from such studies.

To this end we have reviewed the aforementioned articles and have listed most of the expressions used. Table 1 gives the factors which may be used to convert each expression listed into each other expression which is suitable for conversion. We have attempted to use as conversion factors only those values which are available from experimental data. Unfortunately, in many papers these data have not been given. It is usually possible, however, to compare results by converting a more complex expression into a simpler, although not necessarily a better expression. For example, a presentation of the results of a phosphorus study in terms of *dose administered per gram of tissue* will rarely include the data for the phosphorus content of the tissue. *Specific activity*, on the other hand, may be reduced to *percentage of dose per gram of tissue*.

References to each expression listed have been included. References have not been cited for the numerous papers dealing with the general expression *percentage of dose per gram of tissue*. The expressions which cannot be readily converted to others have been listed separately (Table 2).

The recommendations made below were chosen because they seemed generally useful; there are many other expressions which are equally acceptable, but it is desirable to establish conventions so that data may be expressed on a comparable basis. Names have been selected for expressions with an attempt to show what

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TABLE I

FROM \ TO	I % dose gm tissue	II P^{32} tissue average P^{32}	III % dose gm fraction	IV % dose gm fraction	V % dose as fraction gm tissue	VI % dose mg fraction	VII cpm in fraction	VIII cpm mg element	IX cps mg element	X cpm mM element	XI cpm M element	XII % dose mg element	XIII % dose gm element	XIV % dose γ element	XV cpm γ g elem cpm ad kg body wt
I	% dose / gm tissue	-----	$w \cdot 10^{-2}$	$\frac{1}{x} \cdot 10^{3}$	y	1	$\frac{1}{x}$	$Dy \cdot 10^{-2}$	$\frac{D}{C} \cdot 10^{-2}$	$\frac{DA}{C} \cdot 10^{-2}$	$\frac{DA}{C} \cdot 10$	$\frac{1}{C}$	$\frac{10^3}{C}$	$\frac{10^{-3}}{C}$	$\frac{w}{C} \cdot 10$
II	P^{32} tissue / average P^{32}	$\frac{1}{w} \cdot 10^{2}$	-----	$\frac{1}{wx} \cdot 10^{5}$	$\frac{y}{w} \cdot 10^{2}$	$\frac{1}{w} \cdot 10^{2}$	$\frac{1}{xw} \cdot 10^{2}$	$\frac{Dy}{w}$	$\frac{D}{wC}$	$\frac{DA}{Cw}$	$\frac{DA}{Cw} \cdot 10^{3}$	$\frac{1}{wC} \cdot 10^{2}$	$\frac{1}{wC} \cdot 10^{5}$	$\frac{1}{wC} \cdot 10^{-1}$	$\frac{1}{C} \cdot 10^{3}$
III	% dose / gm fraction	$x \cdot 10^{-3}$	$wx \cdot 10^{-5}$	-----	$xy \cdot 10^{-3}$	$x \cdot 10^{-3}$	10^{-3}	$Dxy \cdot 10^{-5}$	$\frac{Dx}{C} \cdot 10^{-5}$ $\frac{D}{z} \cdot 10^{-2}$	$\frac{DxA}{C} \cdot 10^{-3}$ $\frac{DA}{z} \cdot 10^{-2}$	$\frac{DxA}{C} \cdot 10$ $\frac{DA}{z} \cdot 10$	$\frac{x}{C} \cdot 10^{-3}$ $\frac{1}{z}$	$\frac{x}{C}$ $\frac{1}{z} \cdot 10^{3}$	$\frac{x}{C} \cdot 10^{-6}$ $\frac{1}{z} \cdot 10^{-3}$	$\frac{xw}{C} \cdot 10^{-2}$
IV	% dose as fraction / gm fraction	$\frac{1}{y}$	$\frac{w}{y} \cdot 10^{-2}$	$\frac{1}{xy} \cdot 10^{3}$	-----	$\frac{1}{y}$	$\frac{1}{xy}$	$D \cdot 10^{-2}$	$\frac{D}{yC} \cdot 10^{-2}$ $\frac{D}{C} \cdot 10$ $\frac{1}{xyz}$	$\frac{DA}{yC} \cdot 10^{-2}$ $\frac{DA}{yC} \cdot 10$ $\frac{1}{xyz}$	$\frac{DA}{yC} \cdot 10$ $\frac{DA}{yC} \cdot 10^{3}$ $\frac{1}{xyz}$	$\frac{1}{Cy}$ $\frac{1}{xyz} \cdot 10^{3}$	$\frac{1}{Cy} \cdot 10^{3}$ $\frac{1}{xyz} \cdot 10^{6}$ $\frac{1}{xyz}$	$\frac{1}{Cy} \cdot 10^{-3}$ $\frac{1}{xyz}$	$\frac{w}{Cy} \cdot 10$
V	% dose as fraction / gm tissue	1	$w \cdot 10^{-2}$	$\frac{1}{x} \cdot 10^{3}$	y	-----	$\frac{1}{x}$	$Dy \cdot 10^{-2}$	$\frac{D}{C} \cdot 10^{-2}$	$\frac{D}{60C} \cdot 10^{2}$	$\frac{DA}{C} \cdot 10^{2}$	$\frac{DA}{C} \cdot 10$	$\frac{1}{C}$	$\frac{10^3}{C}$	$\frac{10^{-3}}{C}$	$\frac{w}{C} \cdot 10$
VI	% dose / mg fraction	x	$xw \cdot 10^{-2}$	10^{3}	xy	x	-----	$Dxy \cdot 10^{-2}$	$\frac{Dx}{C} \cdot 10^{-2}$ $\frac{D}{z} \cdot 10$	$\frac{DxA}{C} \cdot 10^{2}$ $\frac{DA}{z} \cdot 10$	$\frac{DxA}{C} \cdot 10$ $\frac{DA}{z} \cdot 10^{4}$	$\frac{x}{C}$ $\frac{1}{z} \cdot 10^{3}$	$\frac{x}{C} \cdot 10^{3}$ $\frac{1}{z} \cdot 10^{6}$ $\frac{1}{z}$	$\frac{x}{C} \cdot 10^{-3}$ $\frac{1}{z}$	$\frac{xw}{C} \cdot 10$
VII	cpm in fraction	$\frac{1}{yD} \cdot 10^{2}$	$\frac{w}{yD}$	$\frac{1}{xyD} \cdot 10^{5}$	$\frac{1}{D} \cdot 10^{2}$	$\frac{1}{yD} \cdot 10^{2}$	$\frac{1}{xyD} \cdot 10^{2}$	-----	$\frac{1}{yC}$ $\frac{1}{xyz} \cdot 10^{3}$	$\frac{A}{yC} \cdot 10^{3}$ $\frac{A}{xyz} \cdot 10^{6}$	$\frac{A}{yC} \cdot 10^{3}$ $\frac{A}{xyz} \cdot 10^{6}$	$\frac{1}{yC} \cdot 10^{2}$ $\frac{1}{xyzD} \cdot 10^{5}$	$\frac{1}{yC} \cdot 10^{5}$ $\frac{1}{xyzD} \cdot 10^{8}$	$\frac{1}{yC} \cdot 10^{-1}$ $\frac{1}{xyzD} \cdot 10^{2}$	$\frac{w}{Cyd} \cdot 10^{3}$
VIII	cpm / mg element	$\frac{C}{D} \cdot 10^{2}$	$\frac{wC}{D}$	$\frac{C}{Dx} \cdot 10^{5}$ $\frac{1}{z} \cdot 10^{2}$	$\frac{yC}{D} \cdot 10^{-2}$ $\frac{xyz}{D} \cdot 10^{-1}$	$\frac{C}{D} \cdot 10^{-2}$	$\frac{C}{Dx} \cdot 10^{2}$ $\frac{1}{z} \cdot 10^{-1}$	yC $xyz \cdot 10^{-3}$	-----	$\frac{1}{60}$	A	$A \cdot 10^{-3}$	$\frac{1}{D} \cdot 10^{2}$	$\frac{1}{D} \cdot 10^{5}$	$\frac{1}{D} \cdot 10^{-1}$	$\frac{w}{D} \cdot 10^{3}$
IX	cps / mg element	$\frac{60C}{D} \cdot 10^{2}$	$\frac{60wC}{D}$	$\frac{60C}{Dx} \cdot 10^{5}$ $\frac{60z}{D} \cdot 10^{2}$	$\frac{60yC}{D} \cdot 10^{-2}$ $\frac{60xyz}{D} \cdot 10^{-1}$	$\frac{60C}{D} \cdot 10^{2}$	$\frac{60C}{Dx} \cdot 10^{2}$ $\frac{60z}{D} \cdot 10^{-1}$	$60yC$ $60xyz \cdot 10^{-3}$	60	-----	60A	$60A \cdot 10^{3}$	$\frac{60}{D} \cdot 10^{2}$	$\frac{60}{D} \cdot 10^{5}$	$\frac{60}{D} \cdot 10^{-1}$	$\frac{60w}{D} \cdot 10^{3}$
X	cpm / mM element	$\frac{C}{DA} \cdot 10^{2}$	$\frac{Cw}{DA}$	$\frac{C}{DxA} \cdot 10^{5}$ $\frac{z}{DA} \cdot 10^{2}$	$\frac{yC}{DA} \cdot 10^{-2}$ $\frac{xyz}{DA} \cdot 10^{-1}$	$\frac{C}{DA} \cdot 10^{3}$	$\frac{C}{DxA} \cdot 10^{2}$ $\frac{z}{DA} \cdot 10^{-1}$	$\frac{yC}{xyz} \cdot 10^{3}$	$\frac{1}{A} \cdot 10^{-2}$	$\frac{1}{60A} \cdot 10^{-3}$	-----	10^{3}	$\frac{1}{DA} \cdot 10^{2}$	$\frac{1}{DA} \cdot 10^{5}$	$\frac{1}{DA} \cdot 10^{-1}$	$\frac{w}{DA} \cdot 10^{3}$
XI	cpm / M element	$\frac{C}{DA} \cdot 10^{-1}$	$\frac{Cw}{DA} \cdot 10^{-3}$	$\frac{C}{DxA} \cdot 10^{2}$ $\frac{z}{DA} \cdot 10^{-1}$	$\frac{yC}{DA} \cdot 10^{-4}$ $\frac{xyz}{DA} \cdot 10^{-4}$	$\frac{C}{DA} \cdot 10^{-1}$	$\frac{C}{DxA} \cdot 10^{-1}$ $\frac{z}{DA} \cdot 10^{-4}$	$\frac{yC}{xyz} \cdot 10^{-6}$ $xyz \cdot 10^{-6}$	$\frac{1}{A} \cdot 10^{-3}$	$\frac{1}{60A} \cdot 10^{-3}$	10^{-3}	-----	$\frac{1}{DA} \cdot 10^{-1}$	$\frac{1}{DA} \cdot 10^{2}$	$\frac{1}{DA} \cdot 10^{-4}$	$\frac{w}{DA}$
XII	% dose / mg element	C	$wC \cdot 10^{-2}$	$\frac{C}{x} \cdot 10^{3}$ z	Cy $xyz \cdot 10^{-3}$	C	$\frac{C}{x}$ $z \cdot 10^{-3}$	$Dyc \cdot 10^{-2}$ $xyzD \cdot 10^{-5}$	$D \cdot 10^{-2}$	$\frac{D}{60} \cdot 10^{-2}$	$DA \cdot 10^{-2}$	10DA	-----	10^{3}	10^{-3}	$w \cdot 10$
XIII	% dose / gm element	$C \cdot 10^{-3}$	$wC \cdot 10^{-5}$	$\frac{C}{x}$ $z \cdot 10^{-3}$	$Cy \cdot 10^{-3}$ $xyz \cdot 10^{-6}$	$C \cdot 10^{-3}$	$\frac{C}{x} \cdot 10^{-3}$ $z \cdot 10^{-6}$	$DyC \cdot 10^{-5}$ $xyzD \cdot 10^{-8}$	$D \cdot 10^{-5}$	$\frac{D}{60} \cdot 10^{-5}$	$DA \cdot 10^{-5}$	$DA \cdot 10^{-2}$	10^{-3}	-----	10^{-6}	$w \cdot 10^{-2}$
XIV	% dose / γ element	$C \cdot 10^{3}$	$wC \cdot 10$	$\frac{C}{x} \cdot 10^{6}$ $z \cdot 10^{3}$	$Cy \cdot 10^{3}$ xyz	$C \cdot 10^{3}$	$\frac{C}{x} \cdot 10^{3}$ z	$DyC \cdot 10$ $xyzD \cdot 10^{-2}$	10D	$\frac{D}{60} \cdot 10$	$DA \cdot 10$	$DA \cdot 10^{4}$	10^{3}	10^{6}	-----	$w \cdot 10^{4}$
XV	cpm / mg element / cpm ad / kg body wt	$\frac{C}{w} \cdot 10^{-1}$	$C \cdot 10^{-3}$	$\frac{C}{xw} \cdot 10^{2}$	$\frac{Cy}{w} \cdot 10^{-1}$	$\frac{C}{w} \cdot 10^{-1}$	$\frac{C}{xw} \cdot 10^{-1}$	$\frac{yCD}{w} \cdot 10^{-3}$	$\frac{D}{w} \cdot 10^{-3}$	$\frac{D}{60w} \cdot 10^{-3}$	$\frac{DA}{w} \cdot 10^{-3}$	$\frac{DA}{w}$	$\frac{1}{w} \cdot 10^{-1}$	$\frac{1}{w} \cdot 10^{2}$	$\frac{1}{w} \cdot 10^{-4}$	-----
XVI	cpm / mM elem$^{\gamma}$ / cpm ad / kg body wt	$\frac{C}{wA} \cdot 10^{3}$	$\frac{C}{A} \cdot 10$	$\frac{C}{Awx} \cdot 10^{6}$ $\frac{z}{Aw} \cdot 10^{3}$	$\frac{Cy}{Aw} \cdot 10^{3}$ $\frac{xyz}{Aw}$	$\frac{C}{wA} \cdot 10^{3}$ $\frac{x}{wA}$	$\frac{C}{Awx} \cdot 10^{3}$ $\frac{z}{Aw}$	$\frac{CyD}{Aw} \cdot 10$ $\frac{xyzD}{wA} \cdot 10^{-2}$	$\frac{D}{Aw} \cdot 10$	$\frac{D}{60wA} \cdot 10$ $\frac{D}{60w}$	$\frac{D}{w} \cdot 10$	$\frac{D}{w} \cdot 10^{4}$	$\frac{1}{Aw} \cdot 10^{3}$ $\frac{1}{wA} \cdot 10^{6}$	$\frac{1}{Aw}$	$\frac{1}{A} \cdot 10^{4}$
XVII	cpm / mC elem$^{\gamma}$ / cpm ad / kg body wt	$\frac{CV}{wA} \cdot 10^{3}$	$\frac{CV}{A} \cdot 10$	$\frac{CV}{Awx} \cdot 10^{6}$ $\frac{ZV}{Aw} \cdot 10^{3}$	$\frac{VCy}{Aw} \cdot 10^{3}$ $\frac{xyzV}{Aw}$	$\frac{VC}{Awx} \cdot 10^{3}$ $\frac{xzV}{wA}$	$\frac{VC}{Awx} \cdot 10^{3}$ $\frac{zV}{Aw}$	$\frac{VCyD}{wA} \cdot 10$ $\frac{xyzDV}{wA} \cdot 10^{-2}$	$\frac{VD}{Aw} \cdot 10$	$\frac{VD}{60Aw} \cdot 10$ $\frac{VD}{60w}$	$\frac{VD}{w} \cdot 10$	$\frac{VD}{w} \cdot 10^{4}$	$\frac{V}{Aw} \cdot 10^{3}$ $\frac{V}{Aw} \cdot 10^{6}$	$\frac{V}{wA}$	$\frac{V}{A} \cdot 10^{4}$
XVIII	cpm / mg elem$^{\gamma}$ / cpm ad / gm body wt	$\frac{C}{w}$	$C \cdot 10^{-2}$	$\frac{C}{xw} \cdot 10^{3}$ $\frac{z}{w}$	$\frac{Cy}{w}$ $xyz \cdot 10^{-3}$	$\frac{C}{w}$ $\frac{x}{w} \cdot 10^{-3}$	$\frac{C}{xw} \cdot 10^{-3}$ $\frac{z}{w}$	$\frac{CyD}{w} \cdot 10^{-2}$ $\frac{xyzD}{w} \cdot 10^{-5}$	$\frac{D}{w} \cdot 10^{-2}$	$\frac{D}{60w} \cdot 10^{-2}$	$\frac{DA}{w} \cdot 10^{-2}$	$\frac{DA}{w} \cdot 10$	$\frac{1}{w}$	$\frac{1}{w} \cdot 10^{3}$	$\frac{1}{w} \cdot 10^{-3}$	10
XIX	cpm / gm element / cpm ad / gm body wt	$\frac{C}{w} \cdot 10^{-1}$	$C \cdot 10^{-5}$	$\frac{C}{xw} \cdot 10^{2}$ $\frac{z}{w} \cdot 10^{-1}$	$\frac{Cy}{w} \cdot 10^{-1}$ $\frac{xyz}{w} \cdot 10^{-4}$	$\frac{C}{w} \cdot 10^{-1}$ $\frac{xz}{w} \cdot 10^{-4}$	$\frac{C}{xw} \cdot 10^{-1}$ $\frac{z}{w} \cdot 10^{-4}$	$\frac{CyD}{w} \cdot 10^{-3}$ $\frac{xyzD}{w} \cdot 10^{-6}$	$\frac{D}{w} \cdot 10^{-3}$	$\frac{D}{60w} \cdot 10^{-3}$	$\frac{DA}{w} \cdot 10^{-3}$	$\frac{DA}{w}$	$\frac{1}{w} \cdot 10^{-1}$	$\frac{1}{w} \cdot 10^{2}$	$\frac{1}{w} \cdot 10^{-4}$	1
XX	μc / gm element / μc ad / kg body wt	$\frac{C}{w} \cdot 10^{2}$	C	$\frac{C}{xw} \cdot 10^{5}$ $\frac{z}{w} \cdot 10^{2}$	$\frac{Cx}{w} \cdot 10^{2}$ $\frac{xyz}{w} \cdot 10^{-1}$	$\frac{C}{w} \cdot 10^{2}$ $\frac{xz}{w} \cdot 10^{-1}$	$\frac{C}{xw} \cdot 10^{2}$ $\frac{z}{w} \cdot 10^{-1}$	$\frac{CyD}{w}$ $\frac{xyzD}{w} \cdot 10^{-3}$	$\frac{D}{w}$	$\frac{D}{60w}$	$\frac{DA}{w}$	$\frac{DA}{w} \cdot 10^{3}$	$\frac{1}{w} \cdot 10^{2}$	$\frac{1}{w} \cdot 10^{5}$	$\frac{1}{w} \cdot 10^{-1}$	10^{3}
XXI	cpm / mg elem$^{\gamma}$ / cpm ad / kg	$Cw \cdot 10^{-3}$	$Cw^2 \cdot 10^{-5}$	$\frac{Cw}{x}$	$Cyw \cdot 10^{-3}$	$Cw \cdot 10^{-3}$	$\frac{Cw}{x} \cdot 10^{-3}$	$DwyC \cdot 10^{-5}$	$Dw \cdot 10^{-5}$	$\frac{Dw}{60} \cdot 10^{-5}$	$DwA \cdot 10^{-3}$	$DwA \cdot 10^{2}$	$w \cdot 10^{-3}$	w	$w \cdot 10^{-9}$	$w^2 \cdot 10^{-2}$
XXII	cpm / 10γ	$\frac{C}{D} \cdot 10^{4}$	$\frac{wC}{D} \cdot 10^{2}$	$\frac{C}{Dx} \cdot 10^{7}$ $\frac{z}{D} \cdot 10^{4}$	$\frac{yC}{D} \cdot 10^{4}$ $\frac{xyz}{D} \cdot 10$	$\frac{C}{D} \cdot 10^{4}$	$\frac{C}{Dx} \cdot 10^{4}$ $\frac{z}{D} \cdot 10$	$yC \cdot 10^{2}$ $xyz \cdot 10^{-1}$	10^{2}	$\frac{1}{60} \cdot 10^{2}$	$A \cdot 10^{2}$	$A \cdot 10^{5}$	$\frac{1}{D} \cdot 10^{4}$	$\frac{1}{D} \cdot 10^{7}$	$\frac{1}{D} \cdot 10$	$\frac{w}{D} \cdot 10^{5}$
XXIII	% dose wt / gm elem$^{\gamma}$ g wt	$\frac{CQ}{w} \cdot 10^{3}$	$CQ \cdot 10^{-3}$	$\frac{CQ}{xw}$ $\frac{zQ}{w} \cdot 10^{3}$	$\frac{CyQ}{w} \cdot 10^{3}$ $\frac{xyzQ}{w} \cdot 10^{6}$	$\frac{CQ}{w} \cdot 10^{3}$ $\frac{xzQ}{w} \cdot 10^{-3}$	$\frac{CQ}{xw} \cdot 10^{3}$ $\frac{zQ}{w} \cdot 10^{-6}$	$\frac{CyDQ}{w} \cdot 10^{3}$ $\frac{xyzDQ}{w} \cdot 10^{-6}$	$\frac{DQ}{w} \cdot 10^{3}$	$\frac{DQ}{60w} \cdot 10^{3}$	$\frac{DAQ}{w} \cdot 10^{3}$	$\frac{DAQ}{w} \cdot 10^{6}$	$\frac{Q}{w} \cdot 10^{3}$	$\frac{Q}{w}$	$\frac{Q}{w} \cdot 10^{-3}$	$Q \cdot 10^{-2}$
XXIV	% dose / mM elem$^{\gamma}$	$\frac{C}{A}$	$\frac{wC}{A} \cdot 10^{2}$	$\frac{C}{Awx} \cdot 10^{3}$ $\frac{z}{A}$	$\frac{Cy}{A}$ $\frac{xyz}{A} \cdot 10^{3}$	$\frac{C}{A}$	$\frac{Cx}{Awx} \cdot 10^{-3}$ $\frac{z}{A} \cdot 10^{-3}$	$\frac{CyD}{A} \cdot 10^{-2}$ $\frac{xyzD}{A} \cdot 10^{-5}$	$\frac{D}{A} \cdot 10^{-2}$	$\frac{D}{60A} \cdot 10^{-2}$	$D \cdot 10^{-2}$	$D \cdot 10$	$\frac{1}{A}$	$\frac{1}{A} \cdot 10^{3}$	$\frac{1}{A} \cdot 10^{-3}$	$\frac{w}{A} \cdot 10$
XXV	cpm/mM / cpm ad / gm wt	$\frac{C}{wA}$	$\frac{C}{A} \cdot 10^{2}$	$\frac{C}{xwA} \cdot 10^{3}$ $\frac{z}{Aw}$	$\frac{Cy}{Aw}$ $\frac{xyz}{wA} \cdot 10^{3}$	$\frac{C}{Aw}$ $\frac{xz}{wA} \cdot 10^{3}$	$\frac{Cx}{Awx} \cdot 10^{-3}$ $\frac{z}{Aw} \cdot 10^{-3}$	$\frac{CyD}{Aw}$ $\frac{xyzD}{wA} \cdot 10^{-5}$	$\frac{D}{wA} \cdot 10^{2}$	$\frac{D}{60wA} \cdot 10^{2}$	$\frac{D}{w} \cdot 10^{2}$	$\frac{D}{w} \cdot 10$	$\frac{1}{wA}$	$\frac{1}{wA} \cdot 10^{3}$	$\frac{1}{wA} \cdot 10^{-3}$	$\frac{1}{A} \cdot 10$

TABLE 1

Conversion Factors for Comparison of Expressions Which Have Appeared in the Literature

The factors given convert the expressions listed in the left-hand column to the expressions listed in the top row.

The roman numerals of the expressions correspond to those identifying the references in the bibliography.

Our recommended expressions are shown in bold-face in XXIV and XXV.

The following symbols have been used in the conversion factors:

- A = atomic weight
- C = milligrams of element per gram of tissue
- D = dose administered in counts per minute
- Q = average weight (grams) of a series of animals
- V = valence
- w = weight of animal in grams
- x = milligrams of chemical fraction per gram tissue
- y = total number of grams of tissue
- z = milligrams of element per gram of chemical fraction

they represent, and names previously used for other expressions have been avoided. No one expression is applicable to all cases. Experiments will undoubtedly be performed for which our suggested expressions are inadequate.

The fundamental determination in all these experiments is that of radioactivity. This has been expressed in terms of counts per minute (cpm), counts per second (cps), millicuries (mc), microcuries (μc), or units of electroscopic deflection. It has been frequently calculated as the *percentage of administered dose*. Since the dose influences the final radioactivity, and since the dose should always be known, *percentage of administered dose* appears to be the best method of expression of the radioactivity.

The various expressions are best considered according to the type of experiment in which they are used. The three principal uses of the isotope method are for the measurements of fluid volume, distribution studies, and rate studies.

Fluid Volume Studies

In determining the volume of a fluid with radioactive isotopes there is but one basic calculation, regardless of the volume measured or isotope used. In a typical experiment, a known volume of material containing a known amount of activity is injected into an unknown volume (blood volume, extracellular fluid volume, etc.) and, after sufficient time for proper mixing, the activity of the total fluid volume is determined.

If V = volume being measured
a = activity of the injected substance
v = injected volume
A = activity of the final volume
then

$$v + V = \frac{av}{A}.$$

If v is small in comparison to V, then

$$V = \frac{av}{A}.$$

From this expression it is obvious that the terms in which the activity of the two solutions is expressed are unimportant, as long as they are in identical units.

Distribution Studies

The typical distribution study is carried out by injecting a substance containing radioactive isotope into an animal and observing the activity of various organs or parts of the animal. These results are usually expressed in terms of *percentage of dose per total organ* or *per unit weight organ*. This method of presentation is perfectly adequate for the purpose. Such results have also been reported as *cpm per gram of tissue* or *per gram of chemical fraction*.

Many workers have attempted to determine the weight of material taken up by a given tissue. They calculate this from its activity and the specific activity of the injected material. Such a procedure is valid if the substance being studied is not present in the organism naturally. But if the substance is naturally available to the tissues, the ratio between radioactive and non-radioactive isotopes is changed as soon as the material is diluted by the available body stores; such calculations yield only minimal values. Thus, this method should be reserved for elements which are known definitely to be foreign to the body economy, such as tellurium (*23*) or arsenic (*71*), or for foreign compounds which are known not to be broken down rapidly in the body. It is applicable to *in vitro* studies in which no precursor except the radioactive one is present at the start of the experiment.

The activity of isotope in a tissue has been compared to the average of that in the body (*75*, *76*, *77*, *92*). In small animals this can be done by dissolving the animal and determining

TABLE 2 — Expressions Not Readily Interconvertible

Expressions (References are from the bibliography; all these expressions are identified there by XXVI)	*References*
Fluid Volume	
$\text{Volume} = \frac{\text{Activity of injected substance} \times \text{injected volume}}{\text{Activity of final volume}}$	*1, 14, 24, 43, 54, 61, 66, 74, 86, 87, 95, 106, 108, 145, 149*
Distribution	
(Activity/gram fetus)/(Activity/gram litter)	*42*
Specific activity of tissue/Average specific activity	*4, 60*
Rate	
$\frac{\text{Specific activity of sample}}{\text{Specific activity of injected material}} \times 100$	*137*
Percent tissue isotope found as fraction	*115*
Cpm/Colorimeter reading	*99*
$\frac{\text{Specific activity of sample} \times \text{weight in kilograms}}{\text{Specific activity of injected material} \times \text{cpm administered}} \times 10^8$	*136, 139*
(Cpm/gram tissue)/(Cpm/gram heart muscle)	*131*
$\frac{\text{Specific activity of part of brain}}{\text{Specific activity of cerebellum}} \times 100$	*8*
$\frac{\text{Radioactivity of experimental tissue}}{\text{Radioactivity of control tissue}} \times 100$	*147*
$\frac{\text{Cpm/mg substance in tissue}}{\text{Cpm/mg substance in resting muscle}} \times 100$	*7, 121*
$\left(\frac{\text{Millimicrocuries/cc fluid}}{\text{Millimicrocuries/cc plasma at 3 hours}}\right) \times 10$ / Protein concentration/100 cc plasma	*19*
$\frac{\text{Specific activity of fraction studied}}{\text{Specific activity of inorganic P in fraction}}$	*119*
$\frac{\text{Specific activity of fraction}}{\text{Specific activity of inorganic P in tissue}} \times 100$	*11*
$\frac{\text{Specific activity of fraction}}{\text{Specific activity of acid soluble P in tissue}}$	*152*
(Activity/mg dry nerve)/(Activity/mg dry plasma)	*34*
(Cpm/cc material)/(Cpm/cc serum water)	*27, 134*
(Cpm/unit weight of muscle)/(Cpm/unit weight of serum)	*63*
[(Cpm/mc tissue) × 100]/(Cpm/cc plasma)	*109, 114*
$\frac{\text{Specific activity of fraction studied}}{\text{Specific activity of plasma acid soluble P}}$	*2*
$\frac{\text{Specific activity of fraction}}{\text{Specific activity of plasma inorganic P}} \times 100$	*133*
Specific activity of tissue/Specific activity of plasma	*104, 105*
$\frac{\text{Specific activity of iodine fraction}}{\text{Specific activity of total thyroid}}$	*81, 90, 140*
Activity of sample/Activity of most active sample	*107*
$\frac{\text{Cpm/unit weight of element}}{\text{Cpm/arbitrary fraction}} \times 100$	*53*
Turnover tissue	*30, 141, 153-4*

the average activity directly in a homogeneous sample. However, this method is obviously cumbersome with large animals. Calculations of the average activity of the body from the injected dose and the body weight must take into account the appreciable excretion which occurs with most of the elements used. The comparison of the activity of one fetus of a litter with the average activity for the whole litter is essentially the same as above. The comparison of the specific activity (*vide infra*) of a tissue with the average specific activity of the body falls into the same category. Here the specific activity must be determined directly, obviously ruling out the method for use on larger animals and humans. In all these calculations the units used for specific activity are unimportant, since it appears in both numerator and denominator of the expression.

In studying the formation of a given compound or group of compounds, one can express the results as the *percentage of the dose found per gram of compound* or *group of compounds*. This is preferable to the many similar units—*cpm per milligram of compound* or *per total compound*. If pure compounds are to be used, it seems preferable to express the unit weight as the *millimole*. Of course, where mixtures of unknown composition are under study (such as phospholipid), one must resort to the *milligram* as the unit weight.

Rate Studies

The third major use of isotopes is in the study of rates of reactions. In biological experiments this usually involves the rate of utilization of a substance or the rate of formation of a compound. The concept of *turnover* has been introduced in these studies, *i.e.*, the rate of replacement of substance present by new molecules of that substance. One of the factors affecting the rate of uptake of an isotope is the amount of substance present in the tissues. The *percentage of dose per gram of tissue* or *activity per gram of tissue* method of presenting data does not take this factor into consideration, although it has been used for this purpose by many of the earlier investigators. This has led to the practice of expressing the results of rate studies as *specific activities*. This term is borrowed from the physicist and is defined as the *radioactivity per unit weight of substance*. It is usually expressed in terms of an element, *e.g.*, activity per milligram of phospholipid phosphorus, but it may be expressed in terms of a compound, *e.g.*, activity per milligram glycine or even per gram of tissue. This should be stated clearly in all cases.

The units of weight and radioactivity used depend chiefly upon convenience. For large quantities of very active materials, such as those used in the preparation of trace compounds, specific activity is often expressed as *millicuries per gram of compound*. In tracer studies the activity is best expressed as *percentage of the dose*. The units of weight chosen have been milligram, gram, millimole, mole, milliequivalent, microgram, and ten micrograms. The choice of units is arbitrary and the units are readily interconvertible. Since it is often necessary to compare elements of different atomic weight or compounds of different molecular weight, it seems advisable to follow the custom of the inorganic chemist in using the *millimole* as the preferred unit of weight. Thus the use of an expression called "*Biological Specific Activity*" is recommended:

$$\text{Biological Specific Activity} = \frac{\text{percentage of administered activity}}{\text{mM element or compound}}$$

Whenever this expression is used, the frame of reference should be specified, *e.g.*, Biological Specific Activity of phospholipid phosphorus, or Biological Specific Activity of glycine.

Before leaving the subject of specific activity, it is well to point out that a few authors (*57*, *19*) have used the name in an unorthodox manner to refer to such expressions as *percentage of dose per milliliter*, or

$$\frac{(millimicrocuries/cc\ fluid) \times 10}{millimicrocuries/cc\ plasma\ at\ 3\ hours} \Big/ (gram\ protein/100\ cc\ plasma).$$

We shall show later that there are better expressions for most animal experiments, but of the expressions under discussion this is the only type applicable to *in vitro* work because the body weight is not a factor.

In animal work the effective dose will vary with the weight of the animal. Therefore, several authors have devised expressions to include this variable. Some have attempted to multiply their values by a factor (weight of the animal per average weight of all animals in the group) which would give them a value for a hypothetical "average animal" (*88*, *97*, *98*). Since the average weight will vary in each investigation, this method will not lend uniformity, and makes it difficult to compare studies on different animals.

Another possibility explored by several authors is the use of the expression:

$$\left(\frac{Activity/unit\ wt.\ of\ substance}{Activity\ of\ injected\ material/animal\ wt.}\right) \times factor.$$

Since the activity appears in both the numerator and the denominator, the choice of the units of radioactivity is unimportant, but usually cpm has been used, because it is the value determined directly on the usual counting equipment. Unit weight has been expressed as milligram, gram millimole, or milliequivalent. As pointed out above, our preferred unit is the millimole. Weight of the animal has been expressed in grams, or kilograms, and the factors have ranged from 1 to 10^6. When the factor of 100 is used (it maintains the percentage concept of the expression "Biological Specific Activity"), the use of the gram as the unit of body weight gives convenient numerical values to the expression. Thus, the use of the expression called "*Biological Concentration Coefficient*" is recommended

$$\text{Biological Concentration Coefficient} = \left[\frac{(cpm/millimole) \times 100}{cpm\ administered/gm\ body\ weight}\right]$$

This is probably the most precise and most generally useful unit so far suggested. It is readily transformed into "Biological Specific Activity" for comparison with *in vitro* experiments by multiplying by the body weight.

Many authors have attempted to compare the activity of the tissue under study with a reference tissue. However, the activity of the reference tissue probably varies at a rate that is independent of that of the experimental tissue. Therefore, this method cannot be accepted except in special cases. One of these is the experiment in which the activity of a phosphorus compound is compared with the activity of the inorganic phosphorus of the same tissue (*11*, *119*, *152*), or, as an approximation, with that of the acid-soluble phosphorus. Since this probably represents the immediate precursor of the compound under study, it is most likely the best possible method, but its application is clearly limited. In a similar method, the tooth on the opposite side of the mouth served as a control for the tooth under study (*147*).

A great many investigators have compared the activity of a tissue with that of the plasma. This is a valid comparison if it is made with the plasma constituent which is the precursor of the compound studied and determines its rate of formation. If not, the plasma merely represents a reference tissue and is liable to the criticisms given above. It is often difficult to say whether one substance is the precursor of another and the criteria given by Zilversmit (*153*) are necessary

but not sufficient. When valid, this method is probably one of the best, but its usefulness is limited, and when it is used the "Biological Concentration Coefficient" should probably be given.

Several such expressions have appeared in the literature (Table 2), but the conversion factors used in comparing them are usually not known. However, the error in considering the activity of the serum, serum water, and plasma as the same, and of considering the density of the tissue other than bone to be unity, is probably less than the experimental errors. Therefore, these expressions may all be considered to be essentially:

$$\frac{\textit{activity of tissue}}{\textit{activity of precursor in plasma}}$$

or

$$\frac{\textit{specific activity of tissue}}{\textit{specific activity of precursor in plasma}}$$

For reasons already stated, we prefer the expression containing *specific activity*. We have called this ratio:

"Specific Activity Ratio"

$$= \frac{\textit{specific activity of tissue}}{\textit{specific activity of precursor in plasma}}$$

Comparison of the activity of a tissue with that of an arbitrary sample is acceptable within a single experiment, but the results obtained in this way cannot be compared quantitatively to any other experiments. The activity of a compound has been compared to the activity of the whole tissue, but this has little physiological meaning to recommend it.

Perhaps the most elaborate and precise mathematical interpretation of results is that used by Zilversmit in the determination of turnover time. The reader is referred to his articles for a complete discussion of his excellent, although limited, method (*153*, *154*).

Attempts have been made to correct for the specific activity of the injected material (*136*, *137*, *139*). But authors who have done so, have concluded that with tracers of high specific activity this is not necessary (*135*).

Summary and Conclusions

The methods used for expressing the results of experiments with radioactive isotopes have been indicated and discussed. Constants of proportionality have been calculated for reducing results expressed in different ways to the same terms for purposes of comparison. The following conventions have been suggested for future use:

1. **Volume Studies:**

$$V = \frac{av}{A}, \qquad \text{or} \qquad v + V = \frac{av}{A},$$

if V and v are of the same order of magnitude.

2. **Distribution Studies:**
   a. Percentage of dose/gram of tissue
   b. Percentage of dose/m M of pure compound
   c. Percentage of dose/mg mixture of unknown composition
3. **Rate Studies:**
   a. *in vitro* experiments

Biological Specific Activity

$$= \frac{\text{percentage of activity}}{\text{m M of element or compound}}$$

   b. Animal experiments

$$\text{Biological Concentration Coefficient} = \frac{(\text{cpm/m M element or compound}) \times 100}{\text{cpm administered/gm body weight}}$$

   c. For those experiments which permit the use of the

$$\text{Specific Activity Ratio} = \frac{\text{Specific activity of tissue}}{\text{Specific activity of precursor in plasma}}$$

The Biological Concentration Coefficient should also be given when this expression is used.

* * *

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COUNTERCURRENT SEPARATION OF MERCURY AND COPPER

Concentration of Hg^{204} in Countercurrent Molecular Stills. A series of experiments resulting in the concentration of mercury-204, heaviest of the mercury isotopes, in countercurrent molecular stills has been completed by S. L. Madorsky, P. Bradt, and S. Straus of the National Bureau of Standards. The stills represent an improvement of a design previously developed at the Bureau for isotope separation, in which a number of single-stage stills are so connected that recombination of fractions takes place automatically by gravity feed. In this way, the necessity of making repeated cuts, with consequent reduction in output, is eliminated. The overall operation is such that the light fraction increases in concentration toward the upper end of the still while the heavy fraction increases toward the lower end.

The new molecular distillation column consists of a glass tube having an internal diameter of 21 mm and resting on a nichrome heater. Indentations pressed into the tube on the underside, at right angles to its axis, form a series of pools whose evaporating surfaces are adjacent but at gradually higher levels. Slant roofs over these cups, formed by indenting the upper side of the tube, are cooled by a trough of flowing tapwater so as to condense the vapor. They are so sloped that the condensate from each cup is delivered to the cup immediately above it in the series. Condensate from the sides of the column is guided from cell to cell in the upward direction by means of gutters pressed into the glass column. Each pool has a spillover, which allows liquid to run back in amount equal to the condensed vapor carried forward.

The column has a total of 66 cells of 1-ml capacity and is operated under a vacuum of 10^{-6} mm of mercury. It is provided with large mercury reservoirs at its upper end. The mercury in the upper reservoir is circulated by means of a heating element surrounding a side branch of the reservoir. Since the contents of the upper reservoir are kept in constant agitation, the concentration of lighter isotopes is reduced to a minimum while the heaviest isotope, mercury-204, is concentrated in a small cup at the lower end of the still.

The concentration of mercury-204 in the heavy fraction, as well as its depletion in the upper reservoir, was determined in a mass spectrometer and by density measurements in a small pyknometer. A maximum concentration of 4.66% of the original content of mercury-204 was obtained. This relatively low yield is attributed to the small capacity of the cells and the irregular flow of the liquid by gravity from cell to cell. Use of larger cells with a capacity of 5–10 ml of mercury in a column containing about 250 cells should double the concentration of mercury-204.

The countercurrent molecular stills developed for this work should also prove useful in the separation of other high-boiling mixtures, such as pure hydrocarbons in petroleum and vitamins in animal and vegetable products.

Concentration of Cu^{63} by Countercurrent Electromigration. Concentration of copper-63 was carried out by S. L. Madorsky and S. Straus of the National Bureau of Standards, utilizing the countercurrent electromigration method of isotope separation previously developed at the Bureau. This method, which depends on the difference in mobility of ions of different weight, makes use of an imposed flow of electrolyte through a packing in an electrolytic cell in a direction opposite to the migration of the ions to be separated. If the rate of flow of the electrolytic counter current is made equal and opposite to the average rate of ion transport, then only the lighter isotopic ions make headway against the current while the ions of the heavier isotope are carried back in the opposite direction.

As the singly charged ions, potassium-39, potassium-41, and chlorine-35, had been successfully concentrated by electromigration, the more recent work was done to determine the applicability of the method to a multivalent isotopic ion such as copper. By operation of the electromigration cell for periods of 400 to 500 hours, a small but definite concentration of copper-63 was obtained in the cathode compartment. However, the terminal separation coefficient was only one-third as large as that found for chlorine under similar conditions.

Medical Aspects of Radiation Safety*

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IN A BRIEF DISCUSSION of the medical aspects of radiation safety, what might technically be called the psychosomatic aspects should be emphasized. The subject of radiation hazards has received considerable publicity lately, but I am afraid no attempt has been made to place this special kind of hazard in its correct perspective with regard to other well-known, but less well-publicized, hazards.

There has been—and there is—much too much unthinking panic when the dangers of radiation are mentioned, even in the minds of those who should know better. At least part of this panic is due to confusion between radiation dangers in case of an atomic war and peacetime radiation hazard control in industry and in the laboratory. In the first case, *i.e.*, in case of an atomic war, huge amounts of radiation and radioactive materials may be liberated intentionally in such a way as to overwhelm any protective measures. In the second case, peacetime utilization of nuclear energy, protective measures which are practical and feasible do exist and are being improved daily.

It is important to realize that radiation safety is an integral part of the peacetime program for the investigation and exploitation of nuclear energy. Scientists developing piles or electronuclear machines or working with radioactive materials must consider the safety aspects as one of the chief parts of their problem. Practical applications are and will be possible only if safe methods of operation have been developed. Nevertheless, mention radiation and a scare reaction results. Why?

In the minds of most, the following items seem to be most worrisome:

1. You can't see, smell, feel, or sense radiation in any way. As a result, you never know when you are being exposed to devastating amounts.

2. Radiation penetrates into your very insides and produces all types of terrible, bizarre changes.

3. The effects of overexposure to radiation do not appear for months or years after the exposure has occurred. By that time, it's too late and you are literally cooked.

4. Radiation causes sterility and impotence.

5. Radiation will make your children freaks.

Let's go through this list one by one and see how much is true, half true, and false in these statements.

First—you never know when you are being exposed. True, if you depend on your five senses. This is, of course, also true of many other noxious agents which you cannot detect by your senses in toxic amounts. It's true too of bacteria and viruses. You may be exposed to fatal amounts of these things and never know it.

In peacetime, exposure in a short time to a fatal amount of radiation can only be due to the grossest kind of blunder. Such high intensities of radiation can come only from very special machines or huge amounts of concentrated radioactive materials. The indi-

* From a talk given before the 18th Annual Meeting of the Greater New York Safety Council in April, 1948.

vidual responsible for the handling of such machines or materials, which exist in only a limited number of places will, of course, take exceedingly careful precautions to prevent exposure to everyone, above all, the casual passer-by.

Moreover, in the case of radiation, very sensitive detectors are easily available, and quantitative measurements are not difficult. Ringing bells, flashing lights, alarms of all kinds, may be arranged, to function when any possibility of overexposure exists. It is no feat of strength or endurance to carry detectors around with you, *e.g.* in your pocket. In short, the only problem involved here is the necessity of becoming familiar with the possibilities of radiation detection instruments.

The second point—radiation penetrates into the body and produces terrible, bizarre effects. It is true that, except for alpha radiation and low energy beta radiation, the other familiar types of radiation—gamma radiation, X-rays, and neutrons—can penetrate varying distances into the body. It is easy to forget, however, that ultra-violet, infra-red, radio waves, diathermy waves, as well as certain chemicals in suitable preparations, also penetrate into the body. Gravitation also "penetrates" the body and people, as a result, fall off ladders, *etc.* It is *not* true that the effects of radiation on the body organs are bizarre; rather, they are well-known and can be predicted, and produced in other ways. Whether the effects will be serious is simply a matter of the size of the dose received. It is not an insurmountable problem to prevent exposure to amounts of radiation that will produce serious bodily effects; in fact, it is frequently quite simple and easy to achieve this by interposing distance or suitable absorbers between the body and the source of radiation. Moreover, radiation, or rays cannot be inhaled. Radioactive materials, of course, can be inhaled, if present in the inspired air, or can be ingested, if carried into the mouth. Again, this is no different from the situation with toxic vapors, fumes, dusts, bacteria and viruses. Maximum acceptable concentrations with suitable factors of safety can be established for radioactive materials in air as with other toxic materials and no deleterious effects to any organ of the body will occur if these levels are not grossly exceeded.

The third point—the effects of radiation are delayed for months or years and, by then, it's too late and everything is over with you. If one is referring to large amounts of radiation delivered in a short time, *i.e.* an acute gross overexposure, this is not true, since some immediate effects are always observed. Skin burns, nausea, vomiting and diarrhea, bleeding and blood changes, and secondary infection, will occur immediately or at least within a month. Radiation sickness of this acute character is a serious disease with a high mortality rate. Whether any given individual will die will depend, in the first instance, on exactly what his exposure was—or the size of the dose. Even under such circumstances, however, treatment is not always hopeless. Transfusions and antibiotics are of value, and other drugs, such as rutin, to prevent hemorrhage, will be developed for therapeutic purposes. Unfortunately, it is true that recovery may be incomplete and late sequelae may occur. What these late changes may be is again not a totally unknown question. On the contrary, we are quite sure that significant late or residual effects of such overexposure will be limited to those organs of the body that are peculiarly radiosensitive, namely, the skin, the blood-forming organs, the reproductive organs, specifically the gonads, and the eye. These are the same organs which are

also damaged by chronic overexposure —that is, by amounts of radiation 10 to 50 times the maximum acceptable amounts, repeated daily for several years. From our present point of view, this latter type of overexposure is the more important type and we must consider whether serious damage to those organs can appear insidiously without previous warning. The type of change in these sensitive organs will be the same whether due to chronic overexposure or appearing as a late effect of a serious *acute* overexposure.

Skin cancer resulting from chronic overexposure to radiation does not suddenly appear "out of the blue." It is preceded usually for many years by other much less serious skin changes which are easily observable. When early changes are recognized, if overexposure is stopped, and the skin protected and watched carefully, the appearance of a skin cancer will, in most cases, be prevented. If, as a result of total neglect, a skin cancer does appear, all hope is still not lost since a fair percentage can be cured by standard medical treatment. This, of course, is not to say that skin burns are not very serious matters. They are, but the situation is far from hopeless. Moreover, even in this respect, radiation is not unique. Industrial exposure to chemical carcinogenetic agents is well known, and the possibility of late cancer of the skin exists also in such industries. Moreover, the same possibility of late cancer exists with severe ordinary *thermal* burns.

Blood changes, reflecting changes in the blood-forming organs, also occur as a result of chronic overexposure. Leucopenia, anemia, and thrombocytopenia are the technical terms for decrease in the white blood cells, decrease in the red blood cells, and decrease in the blood platelets, respectively. Fortunately, in human beings, changes in the white cells precede changes in the red cells or platelets by a long time. Early asymptomatic white cell changes are easily discovered in routine blood counts. If development of anemia is missed because of failure to do periodic blood counts, in most cases, removal from exposure will, nevertheless, result in gradual recovery. It is therefore quite simple to prevent any severe irreversible change in the blood-forming organs by performing periodic blood counts. Total neglect, of course, can result in permanent damage to the bone marrow, but the resultant anemia may still be helped by medical treatment. Some tumors have *not* been caused by overexposure to external radiation.

The effect on the eyes as a result of chronic overexposure, particularly to neutrons, may be the production of lens opacities, *i.e.* cataract formation. The early stages of such cataracts are easy to detect if one looks for them. They are slow in developing, do not affect vision until well developed and operative relief is practical.

The effects on the gonads will be discussed under points four and five.

To summarize this third point, it may be stated that the effects of chronic overexposure to penetrating radiation may be insidious, but overexposure of this type can be prevented without difficulty. Early changes can be detected, thereby preventing the appearance of serious late effects such as a skin cancer or uncontrollable anemia.

At this point, there may be the thought that this is all very well, but how about the situation where radioactive materials are inhaled or ingested so that dangerous amounts are deposited in the body and there is no way of getting rid of them? Aren't people like the well-known radium dial painting girls doomed? The answer to this is—unfortunately—yes. If relatively long-lived radioactive materials are deposited in bone, in dangerous amounts,

and cannot be removed from the bone, irreversible changes will eventually occur. Note that all of these conditions must be met. Unfortunately, some of the more common radioactive materials are bone seekers and accumulators, *e.g.* radium, plutonium, strontium, and possibly, carbon. These materials are therefore particularly dangerous and every effort must be made in handling them to prevent excessive amounts from entering the body. Experience in the radium dial painting industry and in the atomic project has proved that safe handling procedures for these materials can be devised. Moreover, it is fairly simple to check routinely the adequacy of handling methods, by air sampling and by instrumental surveys, for contamination produced in various steps of any operation. In addition, excessive accumulation in the body can be prevented by periodic analyses of excreta for the specific materials involved. Analytical techniques to do this are admittedly difficult but nevertheless are feasible — *e.g.* radon determinations in expired air, radium and plutonium determinations in urine and feces.

The fourth and fifth points have to do with the function of reproduction—admittedly a very important function. The simplest point to clear up is the question of impotence—it can be categorically stated that radiation does not cause impotence unless it is part of an overwhelming fatal exposure. Any confusion on this point is due to the mistaken idea that sterility is invariably accompanied by impotence. Sterility and impotence go together only after operative excision. Overexposure to radiation *can* produce sterility, provided the radiation is direct to the testes in males and the ovaries in females, but the maximum acceptable level of radiation exposure can be set well below the amount required to produce sterility. The production of sterility is then possible only as a result of gross overexposure. It is again purely a matter of size of dose and no very subtle considerations are involved. This effect is of no significance when the individual is past the childbearing age. There are no general or constitutional changes of a serious nature to be anticipated as a result of sterility.

It might be well to point out that radioactive materials entering the body must be deposited in the gonads before sterility is a possibility, and to date, no radioactive elements have been found which selectively localize in the gonads. This question of sterility is distinct from the question of genetic changes since, by definition, genetic changes appear only in offspring.

The last item is the possibility of abnormal offspring of individuals exposed to non-sterilizing amounts of radiation. This is a highly technical subject on which the last word has not been said by a long shot. Certain things are relatively clear, however. At first sight, one probably imagines the possibility of gross malformations, like two heads, *etc.*, in the immediate offspring. It is important to emphasize that this type of thing, when it happens as a result of radiation, *practically always* is due to large amounts of radiation delivered directly to a fetus developing in utero. In other words, by mistake, a pregnant woman is given a very gross overexposure.

This is an entirely different type of effect from the so-called genic and chromosenal mutations. The types of genic mutations of most concern in this discussion are the so-called recessive mutations. In order for this type of abnormality to manifest itself, both parents must have the same mutated gene. Under such circumstances, one quarter of the offspring will show the effect. The effects of such mutations are *not* totally unknown quantities, but

correspond exactly to *normally* occurring mutations which appear continuously at a certain frequency rate in any species, including the human species. We are faced with the possibility that the rate of production of harmful recessive genes in the human race will be increased by increased exposure of the population to radiation. For the other effects of radiation mentioned, it was noted that maximum acceptable levels of exposure could be set. The nub of this question of genetic effects is the belief that there is no level below which no effect will be produced, *i.e.* there is no tolerance level, and as a result, all radiation received by the germ plasma throughout all generations is additive in its effects. Expressed in this way, it is fairly clear that the fact of survival of the human race for two million years or so under conditions of exposure to cosmic radiation and natural radioactive materials requires that the germ plasma have the ability to live with low intensities of radiation. The nature of this adjustment process may well be the fact that reverse mutations back to the original normal form of the gene would also be accelerated, so that a new equilibrium number of mutated genes may exist, but at least they will not increase ad infinitum. Moreover, it is to be expected that natural selection, or natural elimination, will cut down the equilibrium number of harmful mutant genes by an unknown factor.

This entire problem is not concerned with any given individual or his immediate offspring but rather with the human race as it presently exists—the population and posterity as a whole. At the present time, actually only a small fraction of the total population is being exposed to radiation in amounts greater than background. The possibility that a large fraction will be so exposed, however, makes this problem of serious import for the future. An evaluation of how serious this may be requires quantitative information not presently available. One might hazard the very gross guess that in order to increase the natural mutation rate by a factor of two, every childbearing individual of this generation would have to be exposed to 50 milliroentgens daily, the presently preferred maximum acceptable level in practice, for 10 to 15 years. Under such conditions, changes might be seen in 150 years.

In this connection, it might be mentioned that radiation is not unique any more as a cause of genetic changes. It has been demonstrated that chemicals, like the mustard gases and various carcinogenetic agents, also can produce genetic changes when germ cells are exposed to their action. It is likely, too, that at least part of the beneficial results of radiation in the treatment of cancer is due to its effects on the genetic material of cells, so that any effective chemical treatment will also have possible genetic consequences.

Radioisotopes in Nutritional Trace Element Studies—II

Techniques are presented for the study of cobalt and manganese metabolism in animals, with a review of results to date

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IN THE FIRST ARTICLE of this series, a general statement of the trace element problem in nutrition was presented, together with a discussion of general radioisotope techniques found advantageous in this type of study. This paper, the second article in the series, deals with the trace elements *cobalt* and *manganese*, primarily from the point of view of the contribution of radioisotope studies to an understanding of their metabolism.

In outlining the present status of the problem, a complete literature review would be cumbersome; therefore, references will be made only to key papers that may serve as a starting point for anyone interested in greater detail, or to recent papers of especial interest. The review of Russell (*1*) is an excellent compilation of the literature to 1944 on trace element observations with farm animals, and can be consulted for support of the statements made in that connection.

The Cobalt Problem

It was about fifteen years ago that cobalt was recognized as a dietary essential for the ruminant. At the present time, cobalt-deficient areas, and diseases of livestock apparently attributable to cobalt deficiency, have been reported in Florida, Michigan, Massachusetts, Wisconsin, New Hampshire and North Carolina, as well as in New Zealand, Australia, New South Wales, Africa, the United Kingdom and Canada. Cattle maintained on forage containing less than 0.04 parts per million (ppm) cobalt on the dry basis will usually develop cobalt-deficiency symptoms, whereas sheep have been reported to require at least 0.07 ppm cobalt in the pasture. The fact that simple-stomached animals apparently do not require cobalt is rather puzzling, but seems to find adequate support. Horses remain in excellent health when maintained on pasture which produces severe deficiency symptoms in cattle and sheep. Rats and rabbits have thrived on diets containing as little as 0.003 and 0.0024 ppm cobalt, respectively (*2, 3*). Another interesting observation is that when cobalt is intravenously administered to cattle and sheep, it is much less efficient therapeutically than when orally administered.

The initial symptom of cobalt deficiency is loss of appetite, and the animals literally starve to death, although surrounded by a luxuriant growth of pasture. Anemia is sometimes observed, although it has not been established whether this is a primary effect, or a secondary result of inanition. The normal levels of cobalt in the blood and tissues are so small that chemical analysis is inadequate to diagnose the condition. The only positive diagnosis at present is observation of animal response to supplemental cobalt.

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In 1929 it was reported that feeding cobalt to rats caused a polycythemia. The literature on cobalt polycythemia up to 1940 was summarized by Schultze (*4*). The increased erythrocyte counts and hemoglobin values represent a true polycythemia not due to a decreased blood volume. In addition to rats, cobalt polycythemia has been produced in dogs, pigs, rabbits, guinea pigs, mice, frogs and chickens. This effect does not occur, however, if the diet is lacking in iron or copper. Orten and Orten (*5*) reported that cobalt administration produces either a diversion of body tissue protein into hemoglobin synthesis or an increased utilization of the limited exogenous supply for this purpose. It has been reported that antipernicious anemia liver extracts accelerate the return to normal of cobalt-polycythemic guinea pigs and rabbits, but do not prevent the polycythemia if given before or simultaneously with the cobalt (*6*). According to Barron (7), the influence of liver extract can be explained by the formation of cobalt complexes, which are eliminated by the bile or urine.

Ascorbic acid also reduces the polycythemic action of cobalt; this is assumed to be due to formation of complexes which are eliminated by the kidneys, or to the reducing properties of the ascorbic acid which prevent the inhibitory effect of cobalt on the enzymes, and re-establish the normal oxidation-reduction potential. It has been suggested that cobalt inactivates enzymes which possess a sulfhydryl group and that this leads to inhibition of the young cells in the red bone marrow, which are then thrown into circulation. There is still no completely acceptable theory for the polycythemic action of cobalt and it may be expected that tracer studies will eventually contribute in major part to an understanding of this action.

In the case of various aerobic and anaerobic microorganisms, animal tissues and tumors, it is interesting that cobalt has been found an effective inhibitor of growth and respiration, and that this physiological action may be overcome reversibly by histidine (*8*, *9*). The chemical mechanism of the cobalt-histidine interaction has been studied by Burk *et al.* (*10*). It has also been reported that an inhibition of growth of young rats due to the inclusion of cobalt in the diet was largely prevented by supplements of methionine, cystine or cysteine (*11*). Ely *et al.* (*12*) observed that intravenous injection of methionine in calves immediately preceding cobalt injection prevented the symptoms of cobalt toxicity. It is evident that cobalt forms complexes with the above amino acids and that this complex formation alters the physiological action of the element. While there is no clear explanation of the biological behavior of cobalt, it seems plausible that it may function by combining with sulfhydryl compounds in tissues and thus interfere with oxidative mechanisms.

A recent paper of Archibald (*13*) on cobalt in cow's milk demonstrates the difficulties involved when such studies are limited to chemical analytical methods. Eight dairy animals were fed 500 mg daily of cobaltous acetate for a period of two months as a supplement in a double reversal method, to determine if such supplementation would raise the amount of cobalt in the milk. The milk from the cows receiving the supplement averaged 2.4 micrograms per liter as compared with 0.6 micrograms per liter when the cows were on the control ration. This type of experiment is indeed formidable because of the difficulties in obtaining reliable analytical values at such low levels and in avoiding contamination; the use of such large doses, and the necessity of working with several animals over a long period of time to establish a significant increase of milk cobalt over the normal, add to the arduousness

and uncertainty in interpreting the results.

As a guide for determining dosage, it is helpful to know the optimum level for the given experiment. In the case of cobalt, a carrier-free or near carrier-free preparation should be used for nutritional studies with those animals having no demonstrated requirement. For the ruminants, a physiological dose would be about 0.1 mg per 100 lb body weight or less. A polycythemic level for rats would be about 40 mg per kg body weight when orally administered, and about 2.5 mg per kg body weight when injected subcutaneously (*14*). The minimum lethal dose for mammals in general is considered as 50–75 mg per kg body weight administered hypodermically. Detrimental effects on dairy cows have been observed from single dosages of 1–5 gm cobalt sulfate, and intravenous injections of 0.5 to 0.6 mg per lb body weight have produced toxicity symptoms in calves (*12*).

Radioisotope Studies with Cobalt

In 1941 Copp and Greenberg (*15*) reported the use of radioactive cobalt with rats. The isotope was prepared by deuteron bombardment of iron in the cyclotron [see Item 7, Table 1 (*16*)]. The radiocobalt was separated from the iron as potassium cobaltinitrite, purified by reprecipitations as silver potassium cobaltinitrite, and prepared for use as a cobalt chloride solution containing 0.1 mg Co per ml. The specific activity was about 5 microcuries per mg Co and the measurements were sensitive to 0.01 microgram Co. In the analytical procedure, 2 mg inert cobalt were added to each sample, the tissue dry-ashed at 600° C, and the cobalt precipitated as the sulfide from the ash solution. The radioactivity of the precipitate was measured with the Geiger counter. Two rats were used, each receiving 10 micrograms radioactive cobalt, one by intraperitoneal injection, the other by stomach tube. With oral administration, about 60% of the dose was excreted in the feces and over 30% in the urine; of the parenterally administered cobalt, over 90% was excreted in the urine and less than 10% in the feces. The glandular organs, particularly the pancreas, liver, spleen and kidneys, showed the highest accumulations of the tissues.

In 1943, Greenberg, Copp and Cuthbertson (*17*), using procedures as described above, demonstrated the appearance of labeled cobalt in the bile, urine, feces, and liver of bile-fistula rats. It was determined that the bile is an important pathway for the passage of cobalt from the body into the intestinal tract, but that it is not the sole path. Of the injected radiocobalt, approximately equal quantities appeared in the bile and in the feces. Low bile and urine values for ingested cobalt reflected the incomplete degree of absorption.

Sheline, Chaikoff and Montgomery (*18*), using cyclotron-produced radiocobalt, followed intravenously injected cobalt in the plasma, bile, and pancreatic juice of dogs provided with bile and pancreatic fistulas. The dosage employed was 10 to 26 micrograms cobalt. The measurements were made by placing one cubic centimeter of the sample in a rectangular dish (2.5 × 6.0 cm) pressed from a thin sheet of aluminum foil. Lens paper was placed in the bottom of the dish to spread the liquid uniformly and to prevent splattering during the subsequent evaporation. After evaporation, the sides of the dish were flattened and the entire aluminum foil wrapped in cellophane and sealed with scotch tape so that only one thickness of cellophane came between the dried material and the wall of the Geiger counter. It was found that of the intravenously injected labeled cobalt only 0.1% and 0.3% appeared in the pancreatic juice after 48 and 70 hours, respectively, whereas 5% of the

dose was collected in the bile during a period of 72 hours.

In 1946, the first of a series of papers was published dealing with studies based on the use of radioactive cobalt with ruminants as well as laboratory animals (*19*, *20*, *21*, *22*). Emphasis was placed on experimentation with the bovine, since essentiality of cobalt for this species had been established and there was the possibility of a species difference between single-stomached animals and ruminants.

The radiocobalt was supplied by the Massachusetts Institute of Technology Radioactivity Center and was prepared by cyclotron bombardment of iron with deuterons. It was obtained as a purified solution of cobalt chloride and consisted of a mixture of three isotopes, $Co^{56,57,58}$. Three preparations were used in these studies: Sample 1 contained 9 mg cobalt with an initial specific activity of 267 micrograms (γ) radium gamma-ray equivalent per mg; Sample 2 contained 5.45 mg cobalt with an initial specific activity of 3,303; and Sample 3 contained 3 mg cobalt with an initial specific activity of 10,680. The measurements were sensitive to 0.004 γ cobalt at 45 days, 0.0006 γ at 20 days, and 0.0001 γ cobalt at 76 days for the three samples, respectively. The differences between preparations were due mainly to the amount of carrier used in the chemical separation of the radioactive cobalt from the target.

Originally the tissue samples were prepared for measurement by dry-ashing the sample and electroplating the cobalt onto a one-inch copper disc. The labeled cobalt plus 10 mg of added cobalt carrier were plated from a solution containing 100 gm ammonium sulfate, 180 ml concentrated ammonium hydroxide and 5 gm ammonium hypophosphite per liter. Electroplating cells for this purpose are now commercially available. When it was necessary to make a chemical separation of the cobalt prior to electroplating, this was done by precipitating with α-nitroso-β-naphthol and dry-ashing the precipitate. It was later found advantageous to make all assays in solution as described in the previous paper (*16*).

It was possible to have all dosages near or below the physiological limits as a result of the high specific activity of the cobalt preparations. With rats, dosages of 0.02 to 26 micrograms cobalt were used for oral administration; with rabbits, 2.4 and 60 micrograms were used for injection and ingestion, respectively; 30 to 60 micrograms were administered to 100-lb swine and 60 to 2,400 micrograms were used with cattle weighing from 100 to 600 lb. About 32 cattle, 2 swine, 20 rabbits, and 100 rats were used in these studies. Since no significant species differences were observed and emphasis was placed upon experimentation with the ruminant, the following discussion applies to observations on the bovine unless otherwise noted.

Excretion of Cobalt: Orally administered cobalt is incompletely absorbed as indicated by the fact that about 80 % of the dose appears in the feces at the same rate as does inert material, whereas about 0.5 % is excreted in the urine and very little is found in the tissues. When the cobalt is intravenously injected, about 62 % is rapidly excreted in the urine and about 33 % in the feces. Thus, the urine represents the main path of excretion of internally metabolized cobalt. From the concentrations of cobalt found in the bile, it can be estimated that 5 to 15 % of the amount appearing in the feces reached there via the bile. This is in general agreement with the findings on bile fistula rats where equal amounts of cobalt were found in the bile and feces. Since the amount reaching the intestinal contents by pancreatic secretion is small, it would seem that the

TABLE 1

Distribution of Labeled Cobalt Administered to Young Calves (*22*)
(Dosage 60 γ of cobalt)

Tissue	*Injection (sacrificed after 17 hours)*		*Oral administration (sacrificed after 5 days)*	
	γ per 100 gm fresh weight per 100 γ dosage	*Percent of dose in whole tissue*	*γ per 100 gm fresh weight per 100 γ dosage*	*Percent of dose in whole tissue*
Pituitary	*	0.	*	0.
Thyroid	0.47	0.017	0.12	0.0047
Thymus	0.22	0.093	0.038	0.021
Adrenals	0.80	0.030	0.24	0.0083
Reproductive organs	0.18	0.044	0.044	0.011
Brain	0.038	0.093	0.014	0.031
Eye	0.049	0.023	0.012	0.0039
Intestinal lymph glands	0.33		0.075	
Heart	0.21	0.30	0.065	0.095
Blood	0.035	0.43	0.012	0.19
Aorta	0.20	0.034	0.070	0.039
Lung	0.42	1.65	0.15	0.79
Trachea	0.24	0.34	0.11	0.076
Kidney	0.97	1.85	0.17	0.33
Bladder	0.19	0.065	0.025	0.0048
" urine	38.3	46.7		
Tongue	0.089	0.057	0.015	0.016
Esophagus	0.11	0.038	0.032	0.087
Abomasum	0.33	0.54	0.060	0.087
" contents	0.0089	0.030	0.0011	0.006
Reticulum	0.16	0.052	0.066	0.023
Omasum	0.23	0.098	0.061	0.021
Rumen	0.12	0.17	0.040	0.045
" and reticulum contents	0.0049	0.032	0.028	0.12
Small Intestine	0.23	1.62	0.043	0.36
" " contents	0.20	1.15	0.033	0.097
Large "	0.21	0.78	0.030	
" " contents	0.86	0.88	0.082	0.12
Pancreas	0.81	0.25	0.085	0.018
Spleen	0.44	0.20	0.070	0.054
Liver	3.56	25.6	0.45	2.48
Gallbladder and Bile	4.16	0.14	0.063	0.0027
Tenderloin muscle	0.040		0.0078	
Gastrocnemius muscle	0.036		0.0078	
Ligament (nuchal)	0.11		0.018	
Cartilage (costal)	0.16		0.11	
Bone (femur)	0.039		0.022	
Red bone marrow (ribs)	0.25		0.054	
White bone marrow (long bones)	0.076		0.023	
Teeth	0.17		0.12	

* Amount in sample less than 0.0004 γ.

intestinal walls must be active in secreting cobalt into the lumen; this will be discussed later on the basis of tissue accumulation studies.

Tissue Distribution of Cobalt: Presented in Table 1 are representative tissue distribution values after administration orally and by intravenous injection of 60 micrograms labeled cobalt to young calves. In addition to the tissues listed, representative samples were taken from the fundus and pyloric regions of the abomasum, the duodenum, jejunum and ileum. With each of these tissues and also the large intestine, the inner surface was removed mechanically for separate measurement and designated as the mucosa; the remainder was designated as muscular tissue.

Pathway of Intravenously Injected Cobalt: Data on the tissue accumulations of radiocobalt lead to the following picture. When cobalt is injected intravenously, about 95 % of the dose is removed from the blood within a matter of minutes; that which remains is found entirely in the plasma since no uptake of the element by the red blood cells has been observed. The cobalt is removed from the blood in large amounts by the kidneys and liver for subsequent excretion in the urine and bile, respectively; smaller amounts are deposited in all of the tissues. High selective accumulation occurs in the glandular organs, particularly the adrenals, thyroid, liver, thymus, intestinal lymph glands and pancreas, whereas the accumulation is low in such tissues as the muscle, bone, ligament, cartilage, eye, white bone marrow and brain. A very small percentage of the injected cobalt is secreted in the milk of the lactating animal.

Very small amounts of injected cobalt appear in the saliva and this accounts for the minute quantities which have been observed in the rumen, reticulum and omasum contents. There is indirect evidence that in the ruminant the true stomach and intestinal mucosa secrete cobalt into the lumen. As already pointed out, it does not seem likely that the amount of injected cobalt appearing in the feces can be entirely accounted for by biliary and pancreatic secretion. Significant amounts of injected cobalt are found in the true stomach contents and not in the contents of the other stomach compartments; while there is always the possibility that this could be due to regurgitation of bile, it seems unlikely. It has also been observed that the true stomach and intestinal mucosa show a greater selective accumulation of injected than of ingested cobalt.

TABLE 2

Tissue Distribution After 5 Days in Young and Mature Cattle of Orally Administered Labeled Cobalt

Tissue	*Relative Concentration Liver = 1000*		*Percentage of Dose in Whole Tissue*	
	Calf	*Adult*	*Calf*	*Adult*
Liver	1000	1000	1	0.4
Kidney	370	425	0.08	0.03
Spleen	240	200	0.03	0.01
Pancreas	170	200	0.01	0.006
Intestinal lymph glands	240	263		
Adrenals	460	<74*	0.01	<0.0002
Blood	70	<4	0.3	<0.01
Muscle	40	<16		

* These values are maxima calculated from the size of sample used and sensitivity of the determination.

Pathway of Orally Administered Cobalt: As indicated previously, absorption of ingested cobalt is very low. In the young calf, tissue distribution of the ingested cobalt parallels that of the injected element. With the adult animals the situation was very interesting;

the cobalt was not found in any of the tissues except those such as the gastrointestinal tract which were in direct contact with the administered material, and the liver, kidney, pancreas, spleen and lymph glands. Table 2 shows the distribution after 5 days in selected tissues of labeled cobalt orally administered to the calf and adult. Where the sample contained no detectable radioactivity, the values are expressed as maxima calculated from the size of the sample used and the sensitivity of the measurement. From the percentage values for the liver, kidney, spleen and pancreas, it would seem that the calf absorbed about twice as much as the adult. The relative concentrations in these tissues as well as in the intestinal lymph glands were about the same for the two ages. It was somewhat surprising that no cobalt was detected in the blood or in the other tissues of the adult.

There are two possible routes of absorption: (*A*) The cobalt could be absorbed directly into the bloodstream, in which case it would enter the portal system and pass through the liver before reaching the general circulation, or (*B*) the cobalt could be absorbed through the central lacteals to enter the lymph system and reach the general circulation via the thoracic duct. The data may be interpreted to indicate that in the adult animal both routes are used, but that the liver and lymph nodes can accumulate cobalt to such an extent that the amount which reaches general circulation is minimized.

Transmission of Cobalt from Dam to Fetus: By the use of radiocobalt, it was possible to show that this element administered to the pregnant cow is transmitted across the placenta, primarily for storage in the liver of the fetus. The amount which reached the fetus was small, about 0.01 % of the total dose administered over a period of two months preceding parturition. The amount of cobalt reaching the unborn animal by this path could suffice for an internal function, but its significance as a reserve for rumen function in later life is open to question.

Effect of Methionine on Cobalt Distribution: On the basis of observations on the effect of certain amino acids on the physiological action of cobalt, a study was undertaken to determine the effect of methionine on the cobalt distribution in the body (*23*). Ten calves were divided into two groups, one group receiving an injection of radioactive cobalt alone, and the other receiving an injection of methionine preceding the cobalt. The animals were sacrificed after times varying from 2 minutes to 12 hours and the accumulation of cobalt in the various tissues was determined. It was found that the methionine had absolutely no effect upon localization of the cobalt. This means that the cobalt-methionine complex in the body is probably transported to and retained by the tissues in the same way as elemental cobalt; the decreased physiological effect is due to the complex formation, rather than the cobalt's not reaching the tissues involved. In studies with rats there was no effect of the various sulfur-containing amino acids on the excretion of labeled cobalt. It would seem that this type of procedure would be most helpful in checking the theory that the influence of liver extracts and ascorbic acid on the polycythemic action of cobalt is due to body elimination of cobalt complexes.

Summary of Nutritional Cobalt Studies: No species differences in the absorption and internal metabolism of cobalt have been observed with rats, rabbits, swine and cattle. The behavior of cobalt in the ruminant is summarized schematically in Fig. 1;

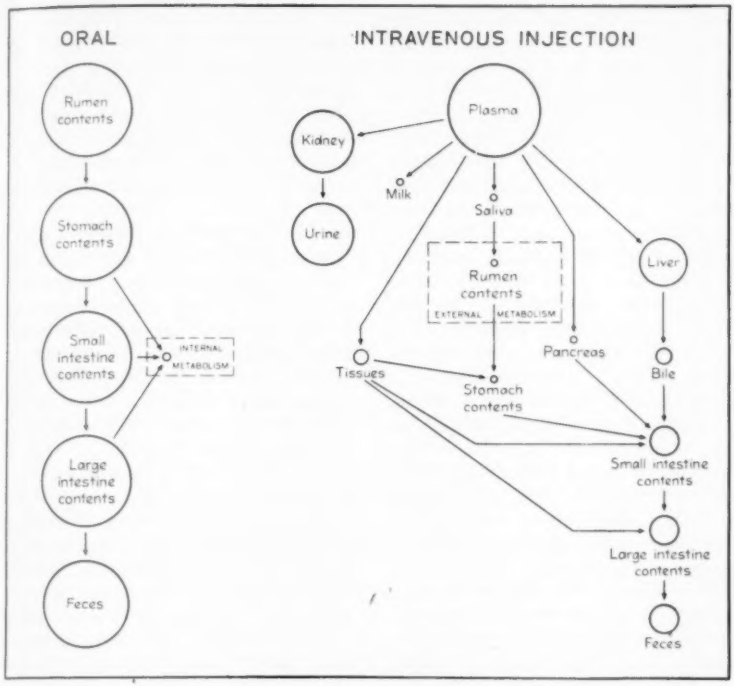

FIG. 1. Schematic representation of cobalt distribution in the ruminant.

the diameters of the circles are roughly proportional to the percentages of cobalt involved. It is noted that only a slight amount of ingested cobalt is available for internal metabolism, whereas the situation is reversed with injected cobalt, there being only a slight amount reaching the rumen contents and this via the saliva. These findings interpreted in view of the observations that the cobalt requirement of non-ruminants, if there is such, is low, and that injected cobalt is not very efficient in relieving deficiency symptoms in ruminants, support the theory that the primary function of cobalt in ruminant nutrition is an external one localized in the rumen contents. On the other hand, the ability of cobalt to stimulate erythrocyte formation and the findings that some cobalt does reach the hematopoietic centers mean that we cannot eliminate the existence of a hematopoietic function of cobalt which may be essential for all species.*

Medical Studies with Radiocobalt: Investigations on cobalt distribution in animals are currently in progress at the University of California, Division of Medical Physics. Preliminary informa-

* Since this paper was prepared, it has been announced that the recently isolated vitamin B_{12}, which is an antipernicious anemia factor, appears to be a cobalt coordination complex [*Science* **108**, 134 (1948)].

tion is available in the AEC declassified document MDDC 1597. These studies were undertaken from the point of view of cobalt polycythemia, and the distribution of cobalt labeled dyestuffs, particularly in relation to tumor tissue.

Co^{60}, produced by the reaction $Co^{59}(n,\gamma)Co^{60}$, was administered intravenously in the form of cobaltous chloride to normal and myeloid leukemic mice. The dosage contained 13 micrograms of Co^{60} with 13.5×10^3 disintegrations per second. The samples were prepared for measurement as follows: The tissues were wet-ashed in HNO_3, $HClO_4$ and H_2SO_4 and all of the HNO_3 and $HClO_4$ were removed by bringing the ash to fuming (SO_3). The ash was partially neutralized with NH_4OH and transferred to the plating cell with 20 ml of 2% $(NH_4)_2SO_4$ in NH_4OH. About 10 mg cobaltous sulfate were added as carrier and the sample plated on copper for 2 hours at 200 m amps. Because of the large amount of ash in bone, intestine and excreta, the procedure was modified, as follows, for these samples: Carrier cobalt was added and the solution precipitated with NH_4OH; since some of the cobalt was carried down with the precipitate, it was necessary to redissolve in concentrated HCl and reprecipitate four times, or until the activity of the residual precipitate was negligible. The supernatants were combined, transferred to the plating cell, $(NH_4)_2SO_4$ added, and the material plated as before. The plates were counted using a thin-mica-window Geiger-Müller tube.

In general, the loss of cobalt from the body and the accumulation in the various tissues were in accord with the findings of the California and Florida workers. Comparing normals and leukemics at six hours, skin, blood, lymph nodes and thymus had a higher concentration of cobalt in leukemics, whereas intestine, stomach, bone, muscle, lung and genitalia showed a lower concentration. The decrease in cobalt concentration was very rapid in all tissues after the first day, although liver, spleen, kidney and pancreas of leukemic mice appeared to lose cobalt less rapidly than did these tissues of normal mice during the first three days.

The Manganese Problem

Although the essentiality of manganese for animal health has been established, there is little known concerning its role in animal biology. The literature on this subject has been reviewed to 1935 by von Oettingen (*24*) and more recently by Maynard and Loosli (*25*), McCance and Widdowson (*26*), and Maynard and Smith (*27*).

In 1931 it was demonstrated that manganese aids lactation and prevents degeneration and atrophy of the testes in the rat. The essential nature of manganese in the prevention of perosis was reported in 1936. Perosis is a nutritional disease of young birds characterized by shortening and thickening of the bones, and is often accompanied by a deformity known as "slipped tendon." This disease has not been recorded as occurring in other vertebrates. It has been reported that certain mineral supplements such as calcium phosphate and ferric hydroxide, which are insoluble at the *p*H of the intestinal tract, tend to remove manganese from solution, probably by adsorption, and therefore have an aggravating effect in the production of perosis. There is also evidence that certain organic dietary factors, one of which is choline, are necessary for the prevention of perosis. A literature survey of perosis, up to 1942, may be found in the review of Jukes and Almquist on avian biochemistry (*28*).

Manganese has been found to serve as activator for certain enzymes including arginase, phosphoglucomutase, carboxylases and peptidases.

A manganese deficiency has been reported to interfere with skeletal development in the rabbit much as in the case of poultry. Smith and Ellis (*29*) have recently reported that 0.3 mg of manganese per rabbit per day is sufficient for normal bone development, but that the minimum manganese intake necessary for maximum growth appears to be somewhat higher. There was some indication that 8 mg of manganese per day was on the borderline of toxicity for rabbits. Skeletal development of the rat is apparently not as sensitive to manganese deficiency as that of poultry or rabbits, although bone abnormalities have been observed in rats born of manganese-deficient females. In first generation rats on a low manganese diet, there has been observed a decrease in bone length, density, breaking strength and phosphatase activity. Lameness in pigs on diets containing 0.0011 to 0.0014 percent manganese, which was preventable by supplements to give 50–60 ppm of manganese, has been reported. Observations are thus accumulating which indicate that manganese may be essential for development of bone in general.

Reid *et al.* (*30, 31*) have recently reported that a basal ration fed to dairy cows when supplemented with $MnSO_4$ in addition to $CaCO_3$ resulted in negative calcium balances, whereas there was a definite tendency toward positive balances when $CaCO_3$ supplementation was used. It was concluded that the $MnSO_4$ depressed the calcium metabolism, resulting in poorer use of the calcium intake by the animal. On the other hand, phosphorous metabolism was not appreciably affected by the various supplements. It was found that lactating cows retained about 155 mg manganese daily regardless of the quantity of the element ingested; the amount of manganese excreted in the feces was found to be directly proportional to the amount of manganese ingested in the range of 622.4 to 1325.6 mg daily. Supplementation of the ration with calcium and various trace elements did not appear to influence significantly the amount of the ingested manganese retained.

There seems little question that any study of manganese metabolism must also take into account the effects of substances such as calcium, phosphorus, vitamin D and choline. A complex system of this type is admirably adapted to radioisotope procedures. Unfortunately, few such experiments have as yet been initiated.

Since the physiological dosage of manganese in nutritional studies with laboratory animals will be of order of magnitude of 0.3 mg per kg body weight or less, this means that a preparation with a fairly high specific activity should be employed.

Radioisotope Studies with Manganese: Greenberg and Campbell (*32*) in 1940, reported on the suitability of radioactive manganese for biological tracer experiments. Mn^{54}, with a half-life of 310 days and prepared by cyclotron bombardment of iron with deuterons, was used. The specific activity of the purified preparation was about 0.1 μc per mg of manganese. The material was administered to the rats as 1 ml of a solution of manganese chloride containing 1 mg of manganese.

In preparation for radioactive assay the tissues were dried and dry-ashed at 500° C. One mg of inert manganese as the sulfate was added to each ashed sample as the carrier for the Mn^{54}. The ash was dissolved in a minimum of dilute HCl and filtered. The total filtrate was evaporated to dryness three times with concentrated HNO_3 to remove the chloride. The residue was then dissolved in hot concentrated HNO_3, and a few crystals of $KClO_3$ were added to precipitate the MnO_2. The

TABLE 3

Distribution of Labeled Manganese (*32*)
(Dosage, 1 mg Mn; sacrificed 75.5 hours after administration)

Tissue	*Oral Administration*		*Intraperitoneal Injection*	
	Percent of dose in whole tissue	*Percent of dose per gm fresh wt*	*Percent of dose in whole tissue*	*Percent of dose per gm fresh wt*
Muscle	0.7	0.007	0.8	0.008
Bone	0.7	0.081	2.0	0.20
Skin	*	*	3.7	0.13
Whole Blood	0.5	0.097	*	*
Liver	0.9	0.14	1.2	0.14
Small intestine	*	*	0.8	0.13
Stomach	*	*	0.8	0.22

* No significant radioactivity detectable in sample.

Other tissues measured but having no activity included heart, large intestine, spleen, kidney, and lung.

Consult (*32*) for calculated error of the values given.

precipitate was filtered off, another mg of inactive Mn was added to the filtrate, and MnO_2 was again precipitated. This second precipitate was collected on the same filter paper so that all of the radioactivity in a single tissue was on the one filter paper. In the case of the bones, it was necessary first to separate the manganese from the large amounts of calcium present. The bone ash was dissolved in dilute HCl and evaporated to dryness. The chlorides were dissolved in water in an Erlenmeyer flask and NH_4Cl was added to the neutral solution. A freshly prepared $(NH_4)_2S$ solution was added to precipitate the manganese sulfide. The flask was filled with boiled water and stoppered. After standing for 12 hours, the precipitate was filtered off. The MnS was dissolved in a small amount of dilute HCl, and then the MnO_2 was separated by the same procedure as in the case of the other tissues. The radioactivity measurements were made on a thin-copper-wall Geiger-Müller counter.

It was found that on a normal diet the rat excreted over 90 % of the manganese within 75 hours, when administered either orally or by intraperitoneal injection. Very little, if any, of the absorbed manganese was excreted in the urine. Table 3 presents the accumulation of the labeled manganese in the various tissues of the rats. After oral administration, 2.8 % of the retained manganese was found in the liver, bone, muscle and blood, with the liver showing the largest uptake. The high values of injected manganese found in the case of the skin and bone are very interesting.

In 1943 this investigation was extended by Greenberg, Copp and Cuthbertson (*33*) to studies with bile fistula rats to determine the importance of the bile as a pathway for the excretion of manganese. It is stated that Mn^{56} was employed; however, since the half-life was designated as 310 days, it is more probable that Mn^{54} was the isotope actually employed.

Table 4 summarizes the data obtained in this study. It may be noted that the amount of intraperitoneally injected manganese appearing in the bile was from one to three times the

TABLE 4

Partition of Labeled Manganese in the Rat in Percent of Administered Dose (*33*)

Diet	*Type of Rat*	*Administration*	*Dose Mg*	*Time Hrs*	*Bile*	*Urine*	*Feces*	*G-I Tract*	*Liver*
Stock	Fistula	Intraperitoneally	0.01	48	27.1	5.4	5.6	21.2	27.1
"	"	"	0.1	48	37.3	3.2	6.5	7.3	11.7
"	"	Orally	0.1	48	1.1	1.2	39.1	42.7	
"	No Fistula	Intravenously	0.01	24		2.1	30.3	21.1	11.8
"	"	"	0.01	48		0.6	49.2	10.2	17.0
Low Manganese	"	Intraperitoneally	0.01	24		0.9	16.0	39.0	26.6
"	"	Orally	0.01	24		0.7	44.0	42.0	1.4

Consult (*33*) for mean deviation of values given.

quantity found in the alimentary tract and feces. This indicates that 50 to 75% of the injected manganese appearing in the feces is probably carried by the bile. The urinary excretion was quite low regardless of the mode of administration. The small amounts of ingested manganese appearing in the bile and liver confirm the poor absorption of this element. The tissue distribution was not altered when the animals were in a moderate degree of manganese deficiency. It is interesting to note that intravenously injected manganese reached the intestinal tract and liver in the same proportions as when the element was administered intraperitoneally.

The function of manganese in preventing perosis in chickens and the relationships thereto of calcium and phosphorous are of interest both from the academic and practical aspects. Mohamed and Greenberg (*34*) placed one group of newly hatched chicks on a synthetic ration containing 2.8 ppm manganese and another group on a control diet containing 59.6 ppm manganese. In about two weeks the chicks on the low manganese diet showed definite evidence of perosis. After the two-week growth period the chicks

TABLE 5

Partition of Labeled and Total Manganese in Manganese-Deficient and Control Chicks (*34*)

Group	*Mode of Administration*	*Labeled Mn in Percent of Dose*			
		Excreta	*Liver*	*Kidney*	*Carcass*
Deficient	Oral	96.3	1.0	0	2.4
"	Injected	65.0	16.0	2.3	10.3
Control	Oral	99.0	0.3	0	0.7
"	Injected	75.6	3.5	2.35	18.2
		Total Mn in mg per 100 g fresh tissue			
Deficient			0.053	0.05	0.023
Control			0.20	0.22	0.07

Consult (*34*) for mean deviation of values given.

were given one ml of a solution containing 15.8 micrograms of labeled manganese dissolved in 0.9% NaCl solution; half of each group received the dosage orally, and the other half by subcutaneous injection. The dosage for each chick, 1 ml of the solution, was equivalent to about 10,000 counts per minute. The radioactive assays were performed according to Greenberg *et al.*, as already described.

Table 5 shows the partition of labeled and total manganese in the manganese-deficient and control chicks which were sacrificed 72 hours after administration of the radioactive material. It is evident that the results are in general agreement with those reported for rats in that the major part of the manganese, whether administered orally or by injection, was excreted by both the deficient and control chicks. Of the tissues studied, the liver showed the highest accumulation. Measurable amounts of the isotope were found in the bone of only the injected deficient chicks.

The fact that only three papers based on the use of radioactive manganese in nutritional trace element studies have been noted in the literature to date is an indication of the virgin possibilities for future work along this line. It is to be hoped that cyclotron production will soon be available so as to permit initiation of such studies.

The next article in this series will deal with the nutritional trace elements copper, molybdenum and zinc.

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An Inexpensive Filter-Cup for Collecting and Counting Active Precipitates*

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THE FILTRATION AND MOUNTING of radioactive precipitates for counting purposes has always been a nuisance. The most common method to date has been the filtration through a Hirsch funnel† and the subsequent transfer of filter paper and precipitate to a paper card preparatory to counting. This procedure is quite troublesome in that a ring of the precipitate usually collects around the edge of the filter paper, thereby making a quantitative transfer of the precipitate difficult.

Armstrong and Schubert‡ have used a small brass Buchner type funnel for this purpose. Their funnel was small enough to enable it to be mounted easily for counting under a thin-window counter. However, for studies in which the precipitates are to be saved for future measurements or in which many precipitates are to be collected it would be quite expensive to have these funnels machined for each sample to be counted.

* This work was supported by the Office of Naval Research.

† C. D. Coryell in "The Uses of Isotopes in Biology and Medicine," pp. 118–133 (University of Wisconsin Press, Madison, Wisc., 1948)

‡ W. D. Armstrong, J. Schubert, *Anal. Chemi.* **20**, 270 (1948)

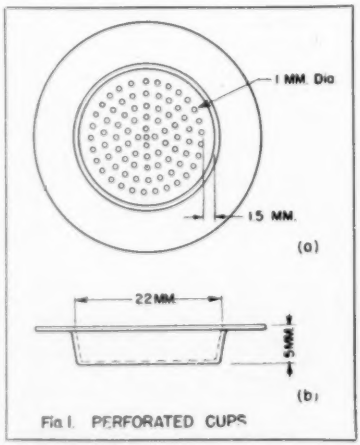


Fig 1. PERFORATED CUPS

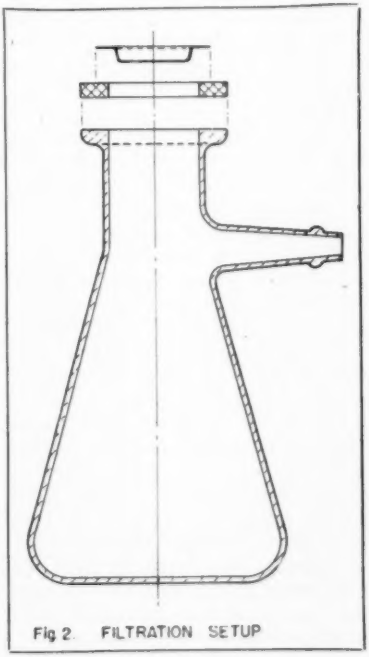


Fig 2. FILTRATION SETUP

This laboratory has for some time used flat aluminum and copper cups (of the size shown in Fig. 1) for evaporating small quantities of radioactive solutions preparatory to counting. These cups have a 2-ml capacity and were purchased from a local firm for $25 a thousand. The cups in use are mounted on a paper card (3 3/16 by 2½ inches) with a one-inch hole in the center. The radioactive material is covered by spreading a thin piece of polystyrene film over the cup, and fastening this to the card on the edges with scotch tape. The source is then ready for counting under a thin-window counter.

These cups have been adapted for use as small funnels, Buchner type. Small holes are drilled or punched by a die in concentric circles in the bottom of the cup (Fig. 1) which is then placed on a rubber ring on top of a filter flask (Fig. 2). Small filter paper is cut to fit with the aid of a set of cork borers or better with an arch punch. In order to prevent the precipitate from being drawn under the paper, rubber cement may be used to cement the filter paper in place. This arrangement is also convenient for the weighing of radioactive precipitate. A preliminary concentration of the precipitate by centrifuging may be convenient.

The aluminum cups are fairly resistant to nitric acid and the copper cups to other strong acids and to alkaline solutions. Students in the MIT radiochemistry course have been using these funnels with very good results and a considerable saving in time.

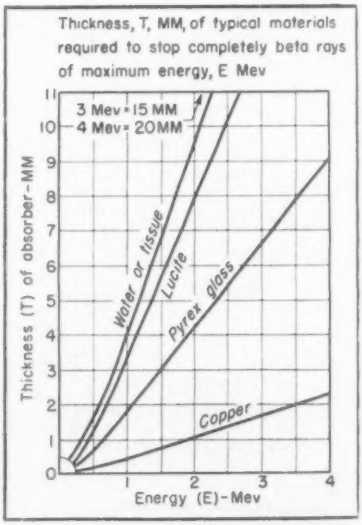
Gravimetric analyses have shown that the retentivity of these funnels with dense filter paper is equal to that of the Gooch-type fine fritted glass crucible for calcium oxalate, and that mechanical loss around the filter paper or collection of precipitate under the edge of the filter paper does not occur. For finely divided precipitates like fresh barium sulfate, loss of $\sim 1\%$ was noted.

Gamma-Ray Shielding Data

THE MATERIAL presented below is from a provisional draft of the report, "Safe Handling of Radioisotopes," prepared for the National Committee on Radiation Protection. The work was carried out under the chairmanship of H. M. Parker together with P. C. Aebersold, L. F. Curtiss, J. G. Hamilton, L. Marinelli, J. E. Rose, and M. M. D. Williams.

The table is a gamma-ray shielding table (prepared by C. C. Gamertsfelder) which is intended to form a guide to rapid erection of temporary shielding structures in the laboratory. Where permanent installations of maximum economy are planned, more detailed calculations by conventional methods are required.

The table can be used as follows: Select column for energy required (use next higher value if the exact value is not given). Entry gives thickness in cm Pb for different source strengths at 1 meter for 8 hours per day to give 100 mr. *Add* algebraically the correc-



tion terms for other working ranges or times, and *multiply* by factor for shield material.

EXAMPLE: An iron shield is required for manipulation of 500 mc of radioactive material emitting 1.8 Mev gamma rays at a minimum working distance of 50 cm, and for two hours per day.

Shield thickness = (7.08 [basic entry]
+ 2.76 [correction for danger range]
− 2.70 [correction for 2 hr/day])
× 1.53 cm Fe [conversion from Pb to Fe]
= 10.9 cm Fe

Activity	Energy (Mev) 0.2	0.5	0.8	1	1.5	2.0	2.5	3.0	6.0
10 mc	− .50	− .86	−1.02	− 1.05	− .83	− .61	− .39	− .13	− .23
20 mc	− .36	− .44	− .33	− .14	+ .33	+ .76	+ 1.06	+ 1.36	+ 1.68
50 mc	− .17	+ .09	+ .59	+ 1.04	+ 1.82	+ 2.55	+ 2.95	+ 3.30	+ 3.58
100 mc	− .03	+ .33	+1.28	+ 1.95	+ 2.97	+ 3.92	+ 4.41	+ 4.79	+ 5.03
200 mc	+ .10	+ .91	+1.97	+ 2.85	+ 4.11	+ 5.27	+ 5.84	+ 6.26	+ 6.47
500 mc	+ .30	+1.46	+2.89	+ 4.04	+ 5.61	+ 7.08	+ 7.76	+ 8.22	+ 8.38
1 c	+ .42	+1.86	+3.57	+ 4.94	+ 6.75	+ 8.43	+ 9.19	+ 9.69	+ 9.82
2 c	+ .56	+2.27	+4.27	+ 5.84	+ 7.87	+ 9.78	+10.63	+11.16	+11.25
5 c	+ .75	+2.81	+5.19	+ 7.03	+ 9.39	+11.58	+12.54	+13.12	+13.17
10 c	+ .89	+3.22	+5.87	+ 7.94	+10.52	+12.94	+13.98	+14.59	+14.60
20 c	+1.03	+3.63	+6.57	+ 8.84	+11.67	+14.31	+15.43	+16.08	+16.06
50 c	+1.21	+4.17	+7.47	+10.02	+13.16	+16.09	+17.33	+18.02	+17.95
100 c	+1.35	+4.58	+8.18	+10.93	+14.31	+17.46	+18.78	+19.51	+19.41

Danger Range	plus	plus	plus	plus	plus	plus	plus	plus	plus
20 cm	+.64	+1.90	+3.22	+4.19	+5.28	+6.31	+6.70	+8.68	+6.70
50 cm	+.28	+ .83	+1.39	+1.83	+2.32	+2.76	+2.93	+3.00	+2.93
1 m	.00	.00	.00	.00	.00	.00	.00	.00	.00
2 m	−.28	− .83	−1.39	−1.83	−2.32	−2.76	−2.93	−3.00	−2.93
5 m	−.64	−1.90	−3.22	−4.19	−5.28	−6.31	−6.70	−6.86	−6.70
10 m	−.92	−2.71	−4.60	−5.98	−7.55	−9.02	−9.57	−9.80	−9.57

Working Time	plus	plus	plus	plus	plus	plus	plus	plus	plus
1 hr. day	−.41	−1.22	−2.08	−2.69	−3.40	−4.06	−4.31	−4.41	−4.31
2	−.28	− .81	−1.37	−1.79	−2.26	−2.70	−2.87	−2.94	−2.87
4	−.14	− .14	− .69	− .90	−1.14	−1.35	−1.44	−1.47	−1.44
8	.00	.00	.00	.00	.00	.00	.00	.00	.00
24	+.18	+ .53	+1.10	+1.17	+1.48	+1.76	+1.87	+1.92	+1.87

Absorber	times	times	times	times	times	times	times	times	times
Pb	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fe	4.75	2.68	2.11	1.75	1.51	1.53	1.53	1.53	1.77
Al*	17.23	7.71	5.43	5.13	4.70	4.25	4.81	5.22	6.01
H_2O	35.00	17.80	12.50	11.15	9.93	10.00	11.20	12.35	14.13

* Or concrete.

NOTES: **1.** Source activity is quoted in millicuries or curies, where 1 curie is that amount of radioactive material that disintegrates at the rate of 3.7×10^{10} dps. However, the table is computed on the further assumption that each disintegration yields one gamma photon of the selected energy. This will lead to inaccuracies whenever the disintegration is complex. More accurate calculations can be made by obvious methods when the disintegration scheme is known.

2. The tabulation ignores increased effective transmission of shields under wide beam irradiation.

3. Where it is preferred to operate in terms of source strength stated in roentgens per hour at 1 meter (rhm) the following conversion to conventional curies, as used above, is made:

Energy (Mev)	0.2	0.5	0.8	1	1.5	2	3	4
Curie equiv. of 1 rhm	20	3.4	2.2	1.8	1.3	1.1	850 mc	710 mc

Theory and Operation of Geiger-Müller Counters—III

THE CIRCUITS

A discussion of various types of external circuits essential for counter operation. Covered in last paper of series are preamplifiers, coincidence circuits, high voltage circuits, battery-operated supplies, scalers, integrating circuits and recorders

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A GEIGER-MÜLLER counter is not a useful device for detecting ionizing radiation unless it is connected to suitable electronic circuits for amplifying and recording the ionizing events. Many types of counters require external electronic aid in controlling the gaseous discharge within the tube and all counters need specially controlled voltage supplies to provide the necessary operating potential. The purpose of this paper is to discuss the various types of essential circuits and also to introduce enough examples of special circuits to provide the reader with ideas for solving specific problems which may be akin to those illustrated here.

Preamplifier Circuits

A circuit of some kind must be provided, before the regular amplifier, which transforms the action of the gaseous conduction within the Geiger-Müller counter tube into a voltage pulse. In tubes which require external quenching of the positive ion secondaries, this preamplifier circuit must provide the necessary quenching action.

The simplest preamplifier circuit is shown in Fig. 1. If a polyatomic gas mixture is used in the counter, the resistance R may be of the order of a megohm or less. This results in a time constant of the circuit less than the deadtime of the counter itself so that the operating voltage is reapplied across the electrodes before the counting field has been established between the electrodes, and the speed of counting is controlled by the positive ion mobility within the tube. The only purpose of the circuit is to provide the counting pulse in the form of the voltage drop across R when current is passing through the counter tube due to the gaseous conduction.

With simple gas filled counters, an external quenching mechanism must be provided to prevent rekindling of the discharge because of secondary electron emission caused by the positive ion bombardment of the cathode. This can be accomplished with the same circuit as shown in Fig. 1 by increasing

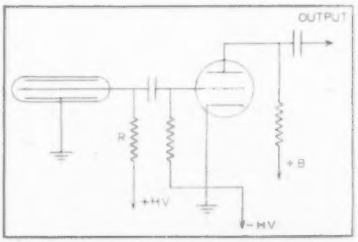


FIG. 1. Simplest preamplifier circuit

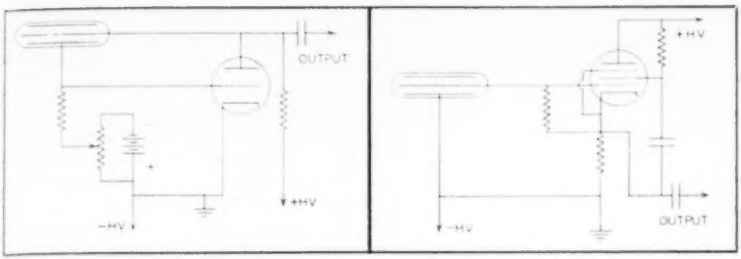


FIG. 2. (left) **A vacuum tube quenching circuit first suggested by Wynn-Williams;**
FIG. 3. (right) **The Neher-Pickering quenching circuit**

the value of R to 10^9 ohms. In this case the time constant of the preamplifier circuit is made so long that the voltage across the electrodes and hence the field within the counter does not reach threshold until after the positive ions have reached the cathode and the subsequently released electrons have been collected by the anode. In this arrangement, therefore, the resolving time of the counting system is controlled by the preamplifier circuit constants, and these lead to a long time constant. Because of this long resolving time this simple circuit can only be used without great loss in response linearity at low counting rates.

A number of vacuum tube quenching circuits have been devised to allow simple gas counters to be used at high counting rates. The first of these, designed by Wynn-Williams (*1*), is shown in Fig. 2. In this circuit the vacuum tube is essentially connected in parallel with the counter. When the counter discharges, the grid of the vacuum tube, which is biased to cutoff, goes positive, and the resulting current through this tube tends to short out the counter, thereby dropping its potential. The advantage of this circuit lies in the fact that, due to the amplification of the vacuum tube, no high resistance is necessary in the input circuit to obtain sufficient drop in the high potential to quench the discharge. Since the time constant of the circuit is given by the resistance and capacitance connected to the grid of the tube, the resolving time can be minimized to the ion travel time across the interelectrode space of the counter, a time of the order of 10^{-4} seconds. The disadvantage of the circuit is that the cathode of the counter is off ground and hence the movement of local conductors in the vicinity of this electrode changes the input capacitance. Since in this circuit the quenching action depends entirely upon the shorting action of the vacuum tube across the high voltage, one can make up for lack of counter discharge current by increasing the amplification of the circuit. As a spectacular though rather useless example of this, there is the case of a counter made from a spoon and fork. The discharge pulses from such an arrangement are too small in general to produce the necessary quenching voltage drop, but the amplification of the Wynn-Williams circuit can be increased at the expense of resolving time by increasing plate resistance to 10^9 ohms. Satisfactory quenching and counting action can thus be achieved (*2*).

A quenching circuit which allows the cathode of the counter to operate at ground potential is the most useful one for routine counter use. Such a circuit, which is now in common use, was designed by Neher and Pickering (*3*) and is shown in Fig. 3. In this circuit the

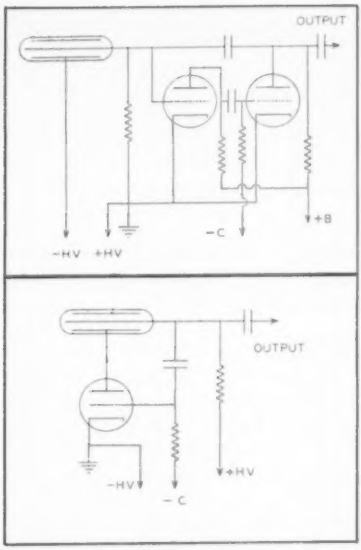


FIG. 4. (above) A multivibrator quenching circuit; FIG. 5. (below) A typical series vacuum tube quenching circuit

vacuum tube is operated so that current is flowing through it when the counter is in a quiescent state. When the counter discharges, the grid swings negative, the current through the tube ceases, and the counter anode and grid potential drop toward that of the cathode, thereby producing the necessary quenching drop in counter potential. This arrangement has the low time constant in the input circuit required to provide minimum resolving time for simple gas filled counters, but has the disadvantage of requiring a power supply capable of providing several milliamperes of continuous current drain.

Although the three quenching circuits so far described, with their many possible modifications, are the most used circuits of this kind, quite a number of other arrangements have been proposed. For example Getting (*4*) has suggested the use of a multivibrator circuit for this purpose. His circuit is shown in Fig. 4. As is typical in multivibrator circuits, one of the tubes is conducting and the other biased to cutoff. The negative pulse from the counter causes the circuit to flip-flop so that the full voltage drop of the vacuum tubes is put across the resistance connected to the counter wire. The subtraction of this voltage pulse from the applied high potential can be adjusted by the circuit constants to quench the discharge. In common with other circuits of this kind, the time constant of the circuit can easily be made less than the inherent resolving time of the counter discharge.

Several quenching circuits have been published in which the vacuum tube is placed in series with the counter tube. Typical of this class of circuit is that due to Yetter (*5*) shown in Fig. 5. When the counter discharges, the pulse from the anode wire swings the grid of the vacuum tube negative, resulting in the choking off of the discharge through the counter. As is true with most of the series type circuits, this arrangement suffers from having the cathode of the counter off ground which produces variable external capacitance, and the output pulse is very small, amounting to only about one volt.

Coincidence Circuits

In the use of counters for physical measurement, it is often important to determine when two or more counters discharge at the same time. A class of circuits has been devised which responds when counter pulses come coincident in time and reject all others. The simplest of these was given first by Rossi (*6*), and is shown schematically in Fig. 6. The vacuum tubes are normally conducting and their plates are connected to a common voltage supply. If a single counter discharges, its negative pulse is fed to the grid of its vacuum

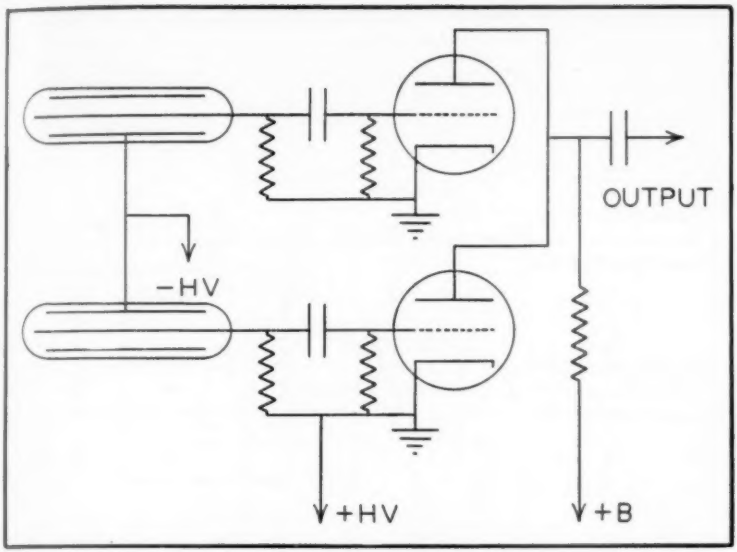


FIG. 6. The Rossi coincidence circuit

tube, essentially cutting that tube off. The current drawn by both tubes changes very little since the other tube still forms a low resistance path. If, on the other hand, both counters discharge simultaneously, both triodes are cut off and a large pulse is passed to the output. This arrangement can be multiplied to any number of coincidence circuits, and, although shown with resistance quenched counters, externally quenching preamplifiers may also be used. For applications in which the space occupied by the vacuum tubes is important, a coincidence circuit of this type, using diodes, has recently been reported (*7*).

For the special case where it is necessary to determine if a predetermined number of counters have discharged in coincidence, the number being less than the total number of counters, Ramsey (*8*) has shown that the circuit in Fig. 7 is useful. One can adjust the bias on the grid of a discriminator tube so that a given size negative pulse on the grid, given by the sum of counters discharging, will drive the tube to cutoff. Thus, an adjustment of grid bias will determine the number of counters which will cause a coincidence count. Although, in principle, the pulses from identical counters should all be just the same, some adjustment is necessary and the variable capacitors shown in the diagram are designed to make the pulses from all counters the same size.

It is sometimes important to be able to arrange a counter system so that events are recorded only when coincidences do not occur. Such circuits, the reverse of what have just been discussed, are called anticoincidence circuits. The diagram of Fig. 6 can be extended to such an arrangement. This is shown in Fig. 8 (*9*). The top two counters are considered the coincidence counters, and the bottom one

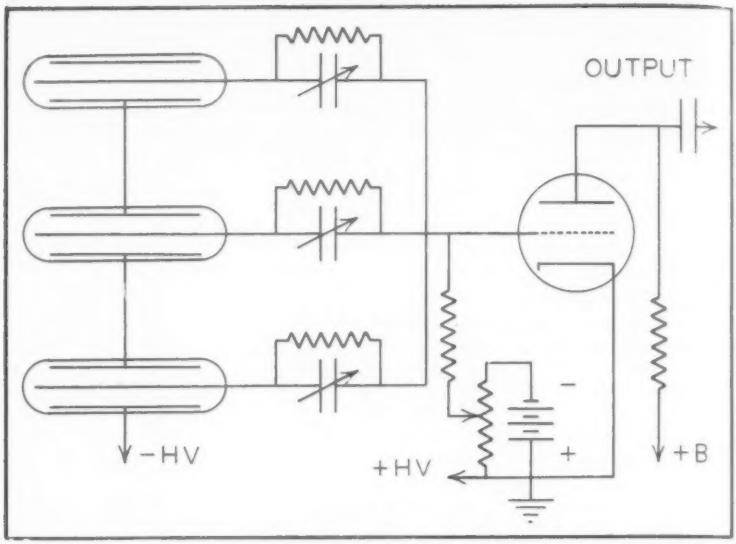


FIG. 7. The Ramsey coincidence circuit

is arranged in anticoincidence. Since whenever a pulse goes through a vacuum tube it is reversed in sign, the obvious way of producing an anticoincidence circuit is to introduce an additional tube into the Rossi circuit. The grid of the first anticoincidence tube receives a negative pulse, and the grid of the second tube a positive one, so that this latter tube cancels out the effect of the other two mixer tubes if all three counters discharge together.

High-Voltage Stabilizers

The Geiger-Müller counter requires a high potential to operate. Since the plateau characteristic is seldom really flat, unless this high potential is very constant, the apparent sensitivity of the counter will vary as the high voltage fluctuates. The simplest method of achieving a constant voltage source would be the use of batteries. However, the usual operating potential lies between 1,000 and 2,000 volts, requiring a very large number of cells, and, even with circuits which draw very little current, the voltage is not constant for any considerable time. For a few special applications, battery supply is still used as a source of high potential, in particular for portable instruments where small high voltage batteries are available, but, in general, even for this application, vacuum tube power supplies are to be preferred.

The simplest types of stabilized high voltage supplies attempt to prevent fluctuations in the primary circuit of the high voltage transformer. This has never proved to be a very satisfactory method because even the small percentage variations of the primary circuit result in large absolute variations of the secondary potential. Nevertheless because of its simplicity it is sometimes used, and takes the form of saturated core transformers or ballast lamps in the input circuit of the high voltage supply.

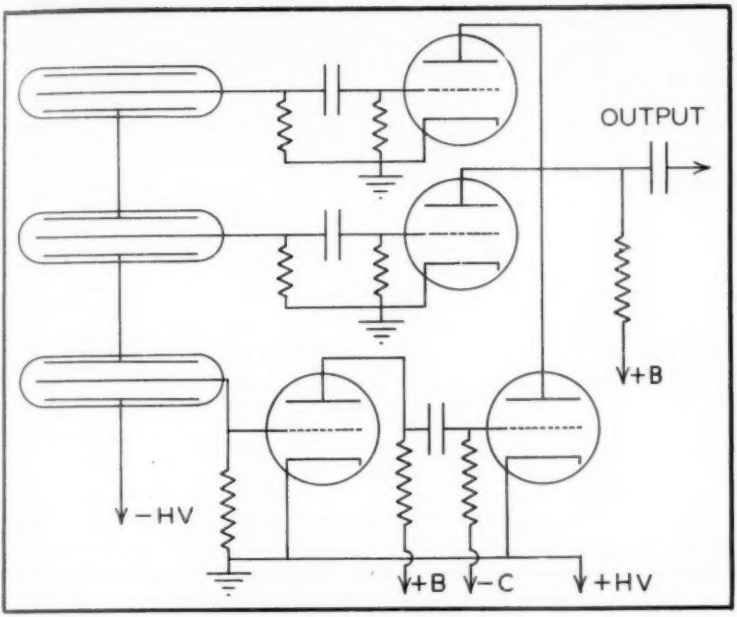


FIG. 8. An anticoincidence circuit

Stabilization of the high voltage itself is by far the most satisfactory method of supplying a counter with a suitable potential source, and this is usually used. There are some very simple types of stabilizers which are not the most effective, but which are useful because of their simplicity. These, in general, use the constant voltage characteristic of a gas discharge to maintain the constant potential. A typical circuit diagram of such a stabilizer is shown in Fig. 9. The neon bulbs are the commercially available ¼ watt size, having an operating voltage of 60 to 90 volts. A suitable number may be added in series to give the desired maximum voltage. Single gas discharge tubes can be built which will be useful in the high voltage range, but since they are not commercially available in this country, the use of many small bulbs is far easier. The stabilization is by no means perfect, and since the characteristics of the gas discharge tubes vary with age, both the voltage and the stabilization change with time. These, of course, are slow effects and they are not serious unless constancy over weeks of operation is desired.

Vacuum tube stabilizers are the most satisfactory for routine operation. There are two principal classes of circuits used in Geiger-Müller counter work, one a bridge-type circuit and the other a degenerative-type circuit. A typical bridge circuit is illustrated in Fig. 10 (*10*). This circuit can be balanced so that the variations in potential between grid and plate have a ratio suitable for maintaining a constant plate current. Since both the grid and plate voltages come from the input high voltage, the voltage drop across the

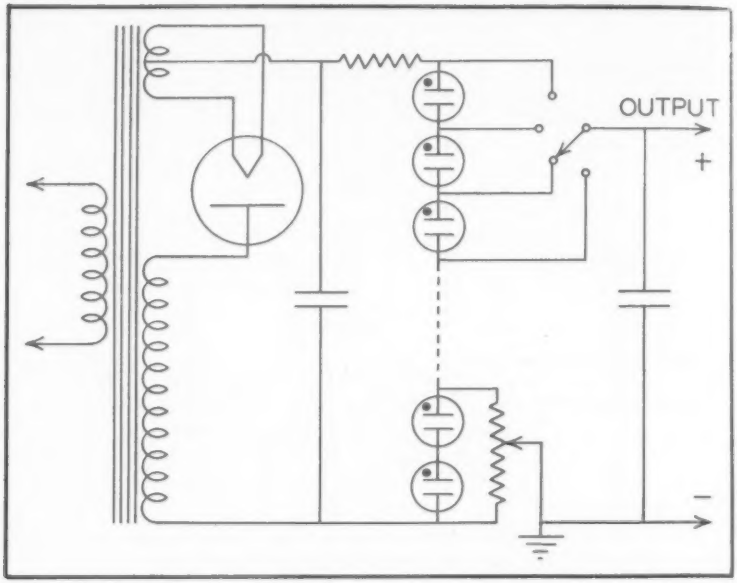
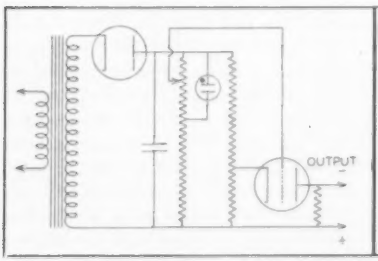


FIG. 9. A neon bulb high voltage stabilizer

load will be stabilized as long as the load resistance stays constant. The regulated voltage is affected by the bias potential on the grid. It is customary to use a neon bulb glow discharge tube to stabilize this bias, but the regulation is then susceptible to the changes which occur in this tube. A battery bias can also be substituted when convenient.

The types of stabilizers which have proved the most useful fall in the class of degenerative circuits. Such a circuit is illustrated in Fig. 11. Here if the output voltage tends to rise, the grid of the lower tube becomes more positive, current is drawn through the plate resistor, biasing negatively the triode in series with the high voltage and hence decreasing the output voltage. This type of stabilizer can be



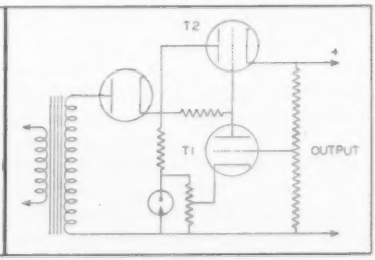


FIG. 10. (left) **A balanced bridge type of high voltage stabilizer;**
FIG. 11. (right) **A degenerative type of high voltage stabilizer**

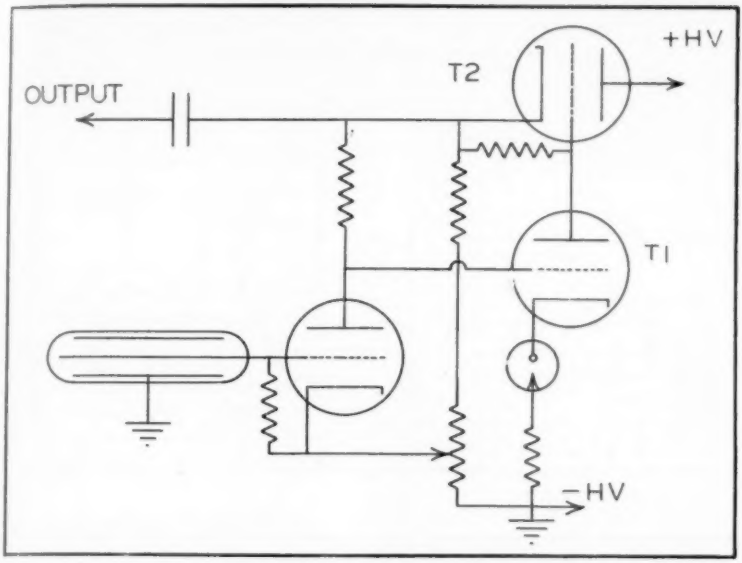


FIG. 12. A combined quenching circuit and degenerative high voltage stabilizer

made to operate over very large variations in voltage, is very stable, has no critical adjustments and has excellent regulation characteristics.

A pre-corona gas discharge shows a very large change in current for small changes in voltage. If such a gas discharge tube is substituted for the lower triode circuit in Fig. 11, a simple and very good stabilizer results (*11*). Since pre-corona discharge tubes are not available commercially, such a stabilizer can be used only in laboratories equipped to make them themselves.

Special High-Voltage Circuits

It is sometimes desirable to have the counter control the output of the high voltage supply rather than to maintain a constant potential across the input to the counter. Two types of circuits for doing this for very different reasons will be discussed.

Bale and Bonner (*12*) have suggested the circuit shown in Fig. 12 which combines the action of a quenching circuit with the type of voltage stabilizer shown in Fig. 11. When the counter discharges, the grid of the vacuum tube connected to the center electrode goes negative. The grid of the tube marked T_1 becomes positive and the voltage across T_2 increases, with a resulting lowering of the potential across the counter. This voltage drop across the counter is great enough to extinguish the counter discharge. This design is particularly advantageous when one is interested in reducing the total number of component parts in the amplifier circuit since it produces very large output signals for each counter breakdown.

In all standard Geiger-Müller counters, much attention is given to obtaining as constant a voltage characteristic as possible. There are some applications, however, where this is inherently impossible. For example,

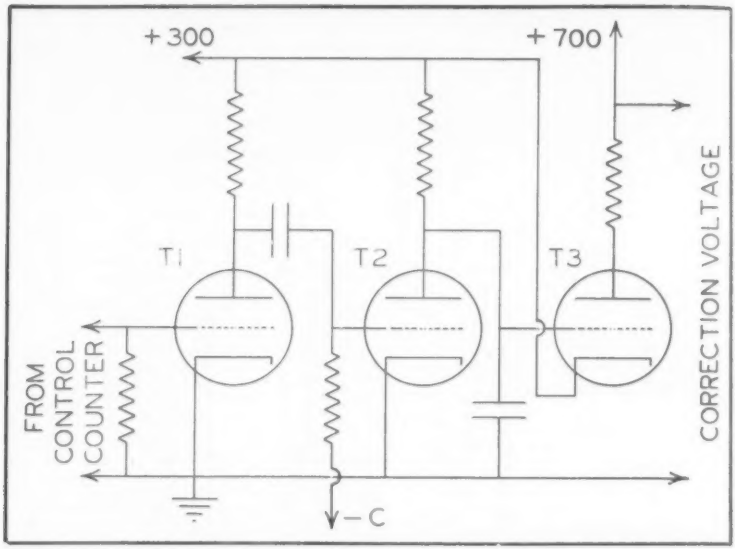


FIG. 13. Special high voltage correction circuit

in studying respiratory problems, the gas composition changes due to the effects of the body, and a method of using counters must be devised to operate in spite of these changes. The principal result of changing gas composition is to shift the threshold voltage. A circuit for allowing the applied voltage to follow changes in counter threshold has been described by Brown, Good, and Evans (*13*). This system consists of two counters open to the same gas supply and connected to the same high voltage supply. One counter was used for measuring the radiation intensity and the other for controlling the output voltage from the power supply. The control counter was contaminated with a beta-ray emitter. It operated at a high counting rate slightly above threshold, where the counting rate changes rapidly with voltage. Changing counting rate was converted into a change in voltage by an integrating circuit which applied a reversed potential to the high voltage supply. Thus if the control counter increased in counting rate it produced a decrease in the voltage applied to both counters. The circuit for accomplishing this is shown in Fig. 13. The pulses from a Neher-Pickering preamplifier are fed into the grid of T_1. These pulses are amplified and sent as positive pulses to T_2, which is normally biased to cutoff. The second tube feeds directly into the third tube through an integrating circuit consisting of its plate resistor, which may be tens of megohms, and the capacitor on the grid of the third tube. The voltage drop across T_2 therefore increases if the counting rate increases and decreases if the counting rate goes down. This correction voltage is subtracted from a stabilized high voltage supply shown in Fig. 11. The circuit is set so that the control counter operates at thresh-

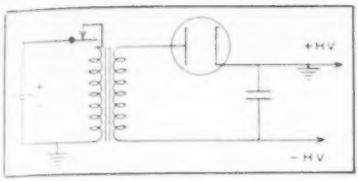


FIG. 14. Mechanical interrupter type of portable high voltage supply

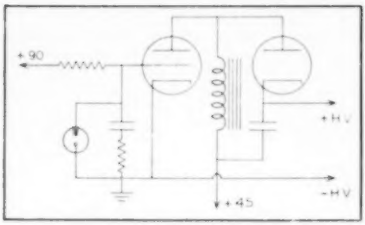


FIG. 15. Relaxation oscillator high voltage supply

old and the measuring counter is set about 100 volts above its threshold. When the circuit is operating, the correction voltage unit will keep the measuring counter 100 volts above its threshold independent of changes both in gas concentration and in its threshold voltage within the over-all voltage range of the correction circuit.

Battery-Operated High-Voltage Supplies

The principal use for battery-operated counting systems is for portable equipment. For this application light weight is desirable, and it is therefore usually impractical to obtain a high voltage from batteries directly because of the heavy weight of enough cells to produce sufficient voltage. A large number of circuits have been suggested in which a high voltage supply is produced from small battery sources. All these circuits contain some type of oscillator which forms a steep wavefront to send a rapidly changing current through an inductance to produce the high voltage.

The simplest method of obtaining the necessarily rapid current change is by means of a mechanical interrupter. Such a high voltage source is illustrated in Fig. 14. The use of a Model T Ford spark coil as the interrupter was proposed by Taft (*14*) and a small buzzer was used by Neher and Pickering (*15*) for the same purpose.

As might be expected, mechanical interrupters are not very satisfactory for routine operation since the contacts are not perfect and frequent adjustments are necessary. To avoid this, various types of electronic oscillators have been designed. Typical of this kind of circuit is that published by Huntoon (*16*), shown in Fig. 15. The neon bulb circuit acts as a relaxation oscillator. The oscillations are amplified by the triode, and the high voltage which then appears across the inductance is rectified by a diode. The filtered high d-c voltage is available across the output capacitor.

Vacuum tube oscillator circuits have also been used. Figure 16 shows one given by Kaiser (*17*) which uses a specially wound air coil transformer. One of the most satisfactory circuits is given in Fig. 17 (*16*). This supply can be made particularly small by using a small relay coil as the inductance and diode-triode r-f amplifier pentode, such

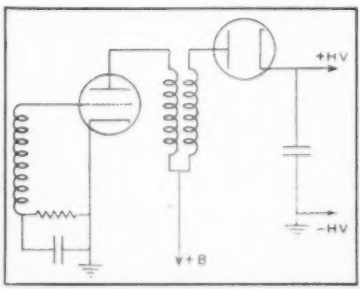


FIG. 16. A vacuum tube high voltage supply

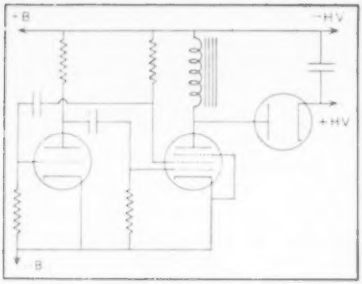


FIG. 17. A battery operated high voltage supply

as a 3A8-GT, so that all the tube elements are contained in a single envelope.

Scaling Circuits

Except in the most elementary applications of Geiger-Müller counters, some type of circuit between the amplified pulses and the output must be provided, largely because mechanical registers are not able to follow faithfully counting rates much above background. One of the common ways of avoiding this difficulty is to insert an electronic scaling circuit which will deliver output pulses in a definite proportion to the input pulses.

Eccles and Jordan (*18*) patented a circuit in 1918 which is fundamental to the design of most scaling circuits used today. This circuit is shown in Fig. 18. To consider its operation, suppose that

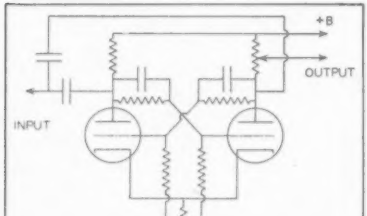


FIG. 18. The Eccles-Jordan scaling circuit

the circuit constants are symmetrical but that the first tube is in a conducting state and the second tube is drawing no current. This means that current is flowing through the first plate resistor and hence the grid of the second tube is biased negatively. Suppose a positive pulse appears at the input. The grid of the first tube will go more positive, which will have no effect. On the other hand, a positive pulse on the grid of the second tube will start this tube conducting. The current drawn through the second plate resistor will bias the first tube negatively, and the end result will be that the first tube will cut off and the second tube will continue to conduct. The entrance of another positive pulse will cause the circuit to flip over again. The output pulse will then be alternately positive and negative, and if the circuit is arranged on the output to accept only pulses of one sign, the number of pulses passed on to the output will be only half the number coming in to the circuit. For this reason, the arrangement is commonly known as a scale-of-two circuit.

Many designs embodying this fundamental circuit have been published, their principal modifications lying in the method of interstage coupling between the scale-of-two units. In coupling between the stages, sufficient amplification must be available both to produce a reliable swing of the trigger circuit, and to make sure that signals fed into the circuit are of only one sign so that when a tube has swung off it will stay off with no tendency to flip back on. Stevenson and Getting (*19*) used a pair of pentodes to feed in pulses, the output of each pentode feeding a grid in the scale-of-two circuit. Lifschutz and Lawson (*20*) published a similar arrangement using a single triode interstage amplifier, capacity-coupled to the two grids of the scaling unit. The simplest method, and one which has proved most satisfactory, is to follow

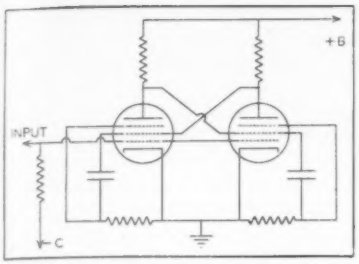


FIG. 19. A direct coupled scale-of-two circuit

the suggestion of Lewis (*21*) in feeding the pulses through a simple rectifier. He used copper oxide rectifiers. At present diode or crystal rectifiers are in more common use.

A circuit using directly coupled pentodes in the scale-of-two circuit (*22*) which has interesting possibilities for use in decade scalers is shown in Fig. 19. The two positions of equilibrium necessary for scaling action can be seen from this diagram. Consider one tube conducting and the other in a non-conducting state. A positive pulse fed into the input will decrease the potential of both the plate of the "off" tube and the screen grid of the "on" tube. The circuit will flip over, turning the "on" tube off, and the "off" tube on.

The system of direct coupling renders this type of circuit useful in scale-of-ten circuits, which have obvious advantages in interpolating, particularly in routine use. A decade scaler of this type is shown in Fig. 20 (*23*). Consider initially that five tubes are conducting and five are cut off, which can be arranged by adjustment of the coupling resistors. In the diagram, the tubes drawn with heavy lines are conducting while the others are off. Since the tubes which are on are drawing current, their plate voltages are low. When a positive pulse is fed into the grids, the pair of tubes at the boundary of the on-off array are the most likely to trip because

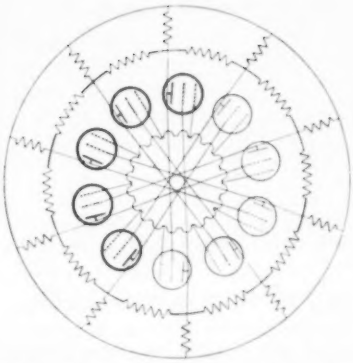


FIG. 20. A decade ring scaling circuit

of the asymmetry of their positions. When a pulse comes in, the off tube at the boundary goes on, and the opposite tube of the pair, which was on, turns off. Thus the whole pattern of on-off tubes moves one position with each input tube. Since there are ten tubes, the total ring becomes a scale-of-ten.

A thyratron has the property that once the plate draws current the grid loses control and the tube cannot be turned off without removing the plate potential from the tube. This characteristic makes the thyratron ideally suited, in principle, to operate in a scale-of-two circuit. Such a use is illustrated in Fig. 21 (*24*). Consider one tube in a conducting state and the

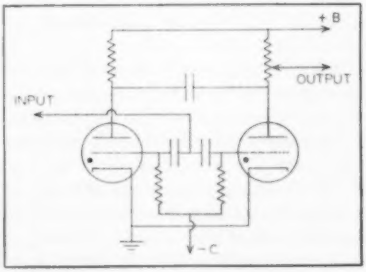


FIG. 21. A thyratron scale-of-two circuit

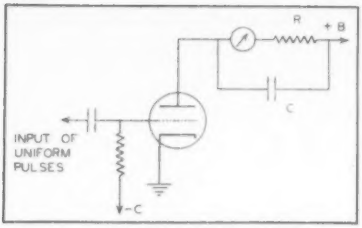


FIG. 22. A simple counting-rate meter circuit

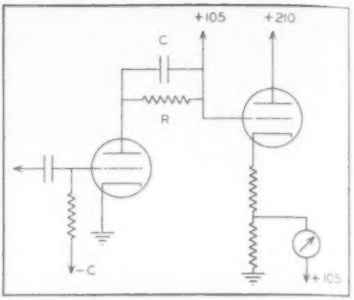


FIG. 23. A vacuum tube voltmeter type of counting-rate meter circuit

other off. If a negative pulse comes into the input no effect can be noted on either tube. In the conducting tube, the grid has lost control, and, in the other tube, making the grid negative does not affect its condition. If a positive pulse comes in, however, the tube which was off starts conducting and the negative pulse thus produced at its plate is fed to the plate of the first thyratron. This negative pulse acts to remove instantaneously the plate potential from this first tube, and hence its discharge is quenched. This is obviously just the desired action for a scaling circuit.

Thyratron scaling circuits suffer from two distinct handicaps. First, the deionization time of the operating gas discharge is about 10^{-4} seconds, and this sets the upper limit for the speed with which this circuit may respond. Secondly, thyratrons are neither very stable nor do they exhibit uniform characteristics, so that the circuits are difficult to keep in adjustment in routine operation.

Scale-of-two circuits are very seldom used singly since it takes higher ratios of input to output rates to be practical. Large numbers of these circuits in series can reduce the output rate to any desired fraction of the input, and at the present time scales from 8 up to 1,024 are in common use.

It is often desirable to be able to interpolate between the input and output counts, particularly when one is using a large scaling factor. Many ways have been suggested for doing this, but probably the most common method in current use is to attach small neon bulbs in parallel with the plate resistors so that the firing of the tube is indicated by the lighting of a neon bulb. Bringing a bank of such neon bulbs to the front panel of the amplifier serves as a convenient method of determining the number of counts which have arrived less than the total number necessary to indicate on the output. Milliammeters, magic eye tubes, and oscilloscopes have all been used as interpolation indicators.

Integrating Circuits

There are some applications in which it is very advantageous to have a continuous indication and record of the actual counting rate. A number of counting-rate meter circuits have been used which integrate the counts over a given interval of time and record the counting rate directly on the output. The fundamental circuit for accomplishing this is very simple. A capacitor is charged up with uniform pulses and the voltage is measured across the capacitor, the rate of its leakage being determined by a shunt resistor.

One of the first counting-rate meter circuits was described by Gingrich,

Evans and Edgerton (*25*). Their integrating circuit is shown in Fig. 22. With a capacitance of 10 microfarads and a resistance of 3×10^6 ohms, the time constant was 30 seconds, which provided a time long enough to avoid excessive fluctuations caused by the random character of the detected radiation. A more flexible system than measuring the changes in the plate voltage of a vacuum tube directly is to arrange a vacuum tube voltmeter circuit to measure the potential difference across the capacitor. Such a circuit is illustrated in Fig. 23.

The great advantage of counting-rate meters is the continuous record obtained of the counting rate. If interference or power failure occurs during runs in which no operator is present, the fact is obvious from the record. The disadvantage of these circuits is the necessity for constant recalibration and checking of the relatively unstable integrating circuit to insure absolutely accurate results.

These integrating circuits lend themselves to design of specialized equipment for various problems. For example, in radioactive tracer work one frequently must use isotopes whose half-life is short compared to the duration of the experiment. Although for occasional samples of this kind the numeral correction for the decay is a simple problem, circuits which correct for the decay automatically can be valuable for large scale routine analysis, particularly when mixtures of isotopes of different periods are involved. Such a device, described by Evans and Meagher (*26*), made use of two counting-rate meters. The output of the counting-rate meters was sent through logarithmic amplifiers and the difference between the two outputs was measured by a vacuum tube voltmeter. As the device was used, a sample under study was measured by one meter and a standard sample of the same radioactive source was measured by the other. The output meter recorded the constant ratio between these two sources as their absolute intensity decayed.

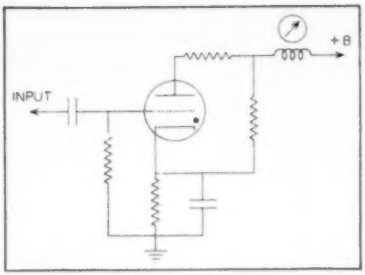


FIG. 24. A thyratron output circuit

Output Circuits and Recorders

The basic information desired from a counter is the intensity of radiation which is to be detected. The outputs from counter circuits give this information in terms of counts per unit time, but the method of displaying this information varies widely.

The most common recording device used on the output of Geiger-Müller counter amplifiers has been the mechanical message register. Since these recorders require a reasonable amount of current through their windings to activate them, power output stages must terminate the amplifier or scaling unit. There is nothing special about the usual output circuits, but for completeness a few common types of circuits can be discussed.

Because of the large currents which can be handled by thyratrons, these gas filled tubes have found frequent application in operating message registers. A typical circuit using a thyratron is given in Fig. 24 (*27*). The arrangement is designed to receive a positive pulse on the grid. When the grid goes positive the discharge strikes, drawing plate current and actuating the mechanical counter. This results

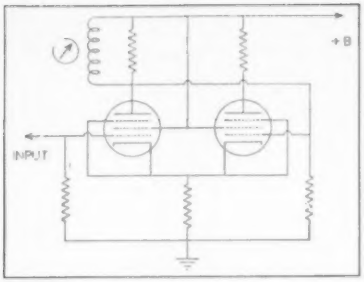


FIG. 25. A multivibrator output circuit

in the charging up of the cathode condenser, thereby causing the arc current to drop to such a point that the grid regains control and the discharge goes out. As soon as the charge on the cathode capacitor leaks off through the cathode resistor the thyratron is ready to function once more.

Multivibrator circuits have also been used to good advantage to operate message recorders. Circuits similar to that shown in Fig. 25 are used in many laboratories for this purpose. The operation of this circuit has been described previously in this paper. The advantage of this type of circuit is that pulses of constant length and height operate the mechanical counters, the most reliable way to run them. Furthermore, the operation of the circuit can easily be made faster than the recorder, a point in its favor over the thyratron output stages in which this cannot always be done.

There are some commercially available message registers which operate with so little current that ordinary triode amplifiers can be used in which the magnet coil is used as the plate resistor. For cases in which more current is necessary, beam power tubes can also serve. It is generally true, however, that the less the current required to operate the mechanical recorder, the slower the action of such a recorder will be, and more scaling units must be used to measure a given counting rate. One therefore must achieve a balance between the ease of operating the recorder and the number of scaling stages to be used.

If mechanical recorders could be built which would count at any speed without loss, the problem of scaling circuits and output amplifiers would be greatly simplified. The fact is, however, that mechanical counting systems are inherently slow devices, particularly in counting random pulses. To a first approximation, the number of pulses a recorder will miss when counting a random phenomenon will be the product of the average counting rate and the resolving time of the mechanical register. For example, for a recorder not to miss more than one percent of the counts at one count per second, it must react to the impulse in at least 0.01 seconds. Commercially available mechanical recorders have resolving times of 5 to 10×10^{-3} seconds. Neher (*28*) has described the construction of such a device which has a resolving time of 8×10^{-4} seconds. By determining the speed where the counter will jam on uniformly spaced pulses one can easily find the resolving time for mechanical counters, and from this information determine the counting rate losses of the device.

Another mechanical output meter which has many advantages over a message register is an electric clock. A clock can be connected so that it starts when the operator begins the run, and is turned off electronically when a certain predetermined number of counts have been collected. For example, if one has a scale-of-1,024, the output from the last scaling tube can actuate a relay to turn off the electric clock, and the clock will therefore read the length of time necessary to reach 1,024 counts. The two principal advantages of this output system are that

it is independent of any mechanical resolving time since the clock runs continuously; and the statistical accuracy of each point is the same because all data are taken on the same number of events.

The output of a counting-rate meter is simply a current measuring device such as a microammeter, so that mechanical resolving time does not enter into this output either. One of the great advantages of the integrating type of meter is the convenience of the output system. Recording galvanometers or pen recorders are the easiest ways to obtain continuous and permanent records of the counting rate.

Conclusion

The circuits which have been discussed in this article have represented types of solutions to the particular problems which come up in the use of Geiger-Müller counters. The details of the circuits, beyond those necessary to understand their operation, have not been included. The actual constructional details, however, can be found in the references which are given with each circuit. It should be obvious that no attempt has been made to include all variations of circuits, nor anything like a complete bibliography, which would be very extensive indeed. The information here should serve as a guide to the types of circuits which are in use in many laboratories, and some special circuits are described as illustrations of the solutions of particular problems.

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Localization of Brain Tumors with Radiodyes*

(Part 1)

CHEMICAL AND PHYSICAL ASPECTS
THE SYNTHESIS OF DIIODO^{131}FLUORESCEIN

By Gerald Boyack,† George E. Moore,‡ and Donald F. Clausen

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RECENTLY MOORE described diodofluorescein made from fluorescein and iodine-131 as an aid in the diagnosis and localization of brain tumors (*1*, *2*). Injections of this material, called diiodo^{131} fluorescein, dissolved in aqueous solution containing 1 mc of radioactivity per 10 cc of 2.0% solution were made in patients suffering from brain tumors. Five hundred to six hundred microcuries of radioactivity were injected intravenously, and it was found that the dye tended to localize in the tumor tissue in a concentration as high as 17 times that in normal brain. By means of a Geiger counter such tumors might then be located. It is the purpose of this paper to report the details of the synthesis of diiodo^{131}fluorescein.

Experimental

The fluorescein used in these experiments is prepared in the usual manner from phthalic anhydride, resorcinol and zinc chloride by fusing. It is purified by reprecipitation as the diacetate. The melting point of the diacetate is 199–200° C (*3*).

The purified fluorescein is iodinated by treatment with iodine chloride (*4*) in acetic acid solution; 0.0031 mole (0.76 gm) of dichloramine T is dissolved in 15–20 cc glacial acetic acid in a 250-cc glass-stoppered flask; 0.0031 mole (0.52 gm) A. R. potassium iodide is added and the flask is shaken until the iodide dissolves and the orange-yellow color of iodine chloride appears. To this solution is added 10–15 mc I^{131} as 4–5 cc of a water solution of potassium iodide. Finally, 0.0015 plus 10% mole (0.56 gm) of purified fluorescein is added, the flask is swirled to mix the contents, and it is then heated one hour on the steam bath. All of the fluorescein dissolves, producing a clear amber solution.

The solution is next poured into 225 cc distilled water and the precipitated diiodo^{131}fluorescein is filtered off on a medium-grade 1.5-inch sintered glass Buchner funnel, using an aspirator. The rest of the glacial acetic acid is used to rinse the iodinated fluorescein solution into the water. The material is pulled dry on the Buchner funnel and then the bulk of it is transferred by means of a glass rod to a 125-cc filtering flask. The Buchner funnel is transferred to this flask and the remainder of the iodinated fluorescein is drawn into the flask with vacuum by the judicious addition of the minimum amount of 5% NaOH. The Buchner funnel is rinsed with a very small amount of water and removed from the flask. Enough 5%

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NaOH to dissolve the iodinated fluorescein is added to the flask and then the *p*H is brought to 8–9 (indicator paper) with 10% HCl. The material is now ready for dilution to any desired concentration, sterilization (autoclave) and injection.

The exact composition of the iodinated fluorescein formed by this procedure has not been proved, but by analogy to the formation of 4,5-dibromofluorescein when fluorescein is bromated (*5*) it is assumed that the product formed is 4,5-diiodofluorescein (each iodine atom ortho to both hydroxyls on the respective resorcinol residues). If the synthesis is carried out properly, the filtrate will be free of iodine, thus affording strong evidence for the formation of diiodofluorescein.

In a typical synthesis, the yield was 0.80 gm of diiodofluorescein, or 81.6%. In a similar run, a trap containing a solution of $NaHSO_3$ acidified with H_2SO_4 was placed in the vacuum line between the flask and aspirator; 13.3 mc of I^{131} were used and a Geiger counter was used to record the yield in terms of I^{131}. The finished diiodo^{131}fluorescein contained 94.8% of the I^{131}, the $NaHSO_3$ trap contained 0.6%, the 250 cc of filtrate contained 2.4%, and the remaining 2.2% was assumed to be mechanical loss.

The synthesis of diiodo^{131}fluorescein is carried out in a room reserved for that purpose. All apparatus used during the synthesis is stored separately until decay of the radioiodine has reduced the danger of radiation to a minimum. The operator wears rubber surgical gloves and remains in the room only during actual manipulation of the product. Lucite shields are employed to protect the operator from possible splashing. Contamination is easily detected since the dye has a brilliant red color. Personnel badges (wrist and lapel) have never revealed a measurable exposure.

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(Part 2)

EXPERIMENTAL EVALUATION OF THE PHYSICAL LIMITATIONS

By James F. Marvin* and George E. Moore

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Minneapolis, Minnesota

THE PROBLEM of localizing brain tumors with radioiodine incorporated into diiodofluorescein requires a critical analysis in order to ascertain which tumors may be expected to be detected and which must necessarily be missed by the Geiger counter.

The limitations of the method are determined by (1) the size of the tumor, (2) the depth of the tumor within the brain, and (3) the ratio of concentration of radiodye in the tumor to that in the surrounding normal brain tissue. The highest concentration of diiodofluorescein has been shown to be in the tumor, with lesser amounts in edematous brain adjacent to the tumor, and the lowest concentration in normal brain tissue. At the optimum time of measurement, concentration of the dye in the tumor has been at least two or

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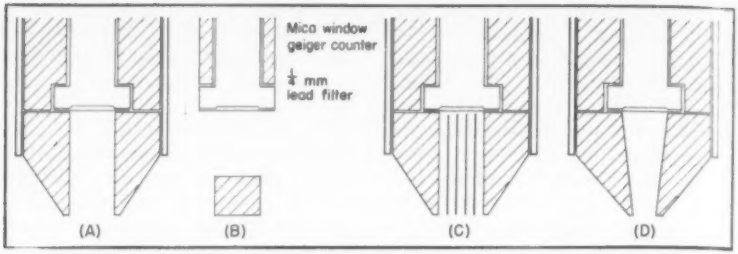

FIG. 1. Lead cones and devices used to shield the Geiger counter tube from radiations originating outside of the tumor. Methods A (cone) and B (lead shield) yield identical results. The grid of C is made of two cylinders of 1/32 inch lead with paper or light wood spacers. The tapered cone of D was not of value in this study of tumors deep in the body

more times that of the surrounding tissue. In clinical cases the range of the concentration ratio has varied from 2:1 up to 17:1. In experimental brain tumors (mice), ratios as high as 80:1 are not uncommon.

Because of the large amount of radioactivity in the brain and the small size of the tumor, it was considered necessary to undertake calculations and phantom measurements to determine the reality of tumor detection and the limits of the method. Calculations and first measurements were made with a flat dish phantom 10 centimeters in depth and larger in area than the total area covered by the lead cone of the counter system. Finally, check measurements were made on a skull phantom. Tumors were represented by volumetric flasks of suitable volume filled with iodide solution with twice the concentration of I^{131} of the surrounding liquid. Total volume in the dish was kept the same by withdrawing liquid equal to the tumor volume.

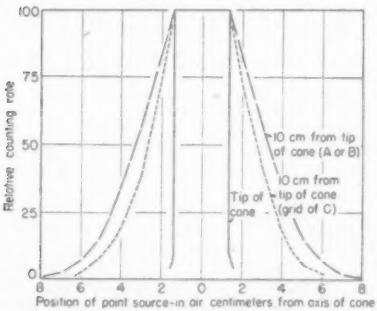
100
75
50
25
0
Relative counting rate
10 cm from tip of cone (A or B)
10 cm from tip of cone (grid of C)
Tip of cone
8 6 4 2 0 2 4 6 8
Position of point source-in air centimeters from axis of cone

FIG. 2. Directional sensitivity of the counters for a point source of radioiodine in air. Figure gives relative counting rate as point source is moved away from (and perpendicular to) the axis of the cone in the plane of the cone tip and in the plane 10 centimeters from the cone tip. Inner dashed curve shows improved directional counting with the grid of C

The Geiger counter directional devices and directional sensitivity are shown in Figs. 1 and 2. The directional sensitivity of the counter with the lead cone of A in Fig. 1 was the same as that obtained by the method B in Fig. 1, which involves counting without a lead cone with and without a lead mask. The counting rate with the lead mask in place is considered the background rate. In this method, total counts must, of course, be great enough to make the difference between these two high counts of significance statistically. Use of a grid (C in Fig. 1) similar in construction to the Lysholm grid was of value in reducing the spread of the "detection cone" but, in the present case, it seriously reduced the counting rate. Use of a tapered cone (D in Fig. 1) enhances the effect of active material near the surface at the expense

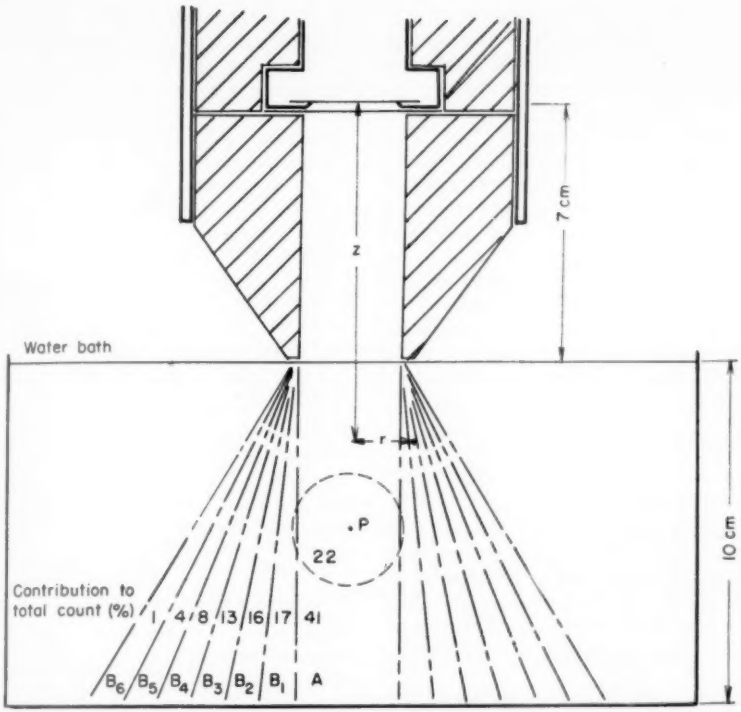

FIG. 3. Directional sensitivity of the counter for iodine in the 10-cm depth water phantom. Lettered zones indicate the portions of the phantom which contribute to the total count; the contribution of each zone is given in percent of the total count. Increase in total count is given for a 40-cc "tumor" with center at point *P*

of that in the tumor area. This design seems to be definitely contraindicated. Likewise is contraindicated any counting system of low efficiency such as the multiple bead counter suggested for directional counting.

Calculations

Figure 3 represents a cross-sectional view of the counter, the flat phantom 10 centimeters in depth and the "detection cone" or area occupied by active material whose radiations are able to reach the Geiger counter. (The relative efficiency of the counter for a point source of I^{131} placed in the central cylindrical zone (A) and in each of the cones B_1 to B_6 was obtained from Fig. 2. Calculations were made of the contribution to the total counting rate of the radiations from the active material in each of the marked zones (Fig. 3) of the solution containing I^{131}. These were made separately for the cylindrical zone, of relative efficiency 1.0, and for the cones, of lower relative efficiency.) Formulas used involved the constants:

r,z cylindrical coordinates

r = distance from point x to axis of cone

z = distance along axis of cone from mica window to point x

K = counts per minute per microcurie at point P (12 cm from counter) (72 for mica window with 0.25 mm lead filter)

ρ = microcuries per cubic centimeter of solution

μ = absorption coefficient of gamma rays of I^{131} (in water) (absorption experiments yielded a value $\mu = 0.069$ cm^{-1})

ϵ = relative efficiency of counter (obtained from Fig. 2)

For the cylinder ($\epsilon = 1.0$), integration in cylindrical coordinates between the limits 7 to 17 cm in z and 0 to 1.4 cm in r yields the result

$$\text{Cpm} = \int_7^{17}\int_0^{1.4} K \cdot \rho \cdot \left(\frac{12}{z}\right)^2 \cdot e^{-\mu(z-7)} \cdot 2\pi r \cdot dr \cdot dz$$

$$= 55 \cdot K \cdot \rho$$

For the cones (use mean value of ϵ for each zone), integration was carried out between the limits 7 to 17 cm in z and the limits in r which represent the edges of the respective cones. The formula and the results in cpm due to each cone follow.

$$\text{Cpm} = \int_7^{17}\int_{1.4+(z-7)\tan\theta_1}^{1.4+(z-7)\tan\theta_2} K \cdot \rho \cdot \epsilon \cdot \left(\frac{12}{z}\right)^2 \cdot 2\pi r \cdot dr \cdot dz$$

Cone	*Efficiency*	*Cpm (multiply by $K \cdot \rho$)*
B_1	0.83	37.7
B_2	0.56	34.0
B_3	0.37	28.2
B_4	0.20	18.4
B_5	0.08	8.6
B_6	0.02	2.4
	Total	129.3 $K \cdot \rho$

Correction for absorption of gamma rays in water reduced this value to 62% or 80 $K \cdot \rho$.

For the spheres representing tumors, integration involved the additional constant R, the radius of the sphere. Center of the sphere was assumed to be located 12 cm from the counter (5 cm depth in water). As concentration of I^{131} was twice that of the surrounding liquid and equal volume of liquid was removed before inserting the "tumor," the expected increase in cpm is represented by the integral.

$$\text{Cpm} = \int_{(12-R)}^{(12+R)} e^{-\mu(z-7)} \cdot K \cdot \rho \cdot \left(\frac{12}{z}\right)^2 \cdot \pi[R^2 - (12 - z)^2]dz$$

$$= 0.72 \cdot \text{volume} \cdot K \cdot \rho$$

For the 40-cc tumor (radius = 2.15 cm), the increase is calculated to be 29 $K \cdot \rho$. For the 20-cc tumor the increase should be 14.5 $K \cdot \rho$. Expected cpm are, therefore, for the bath, the sum of that for the cylinder and the cones, or as follows:

	Cpm	*Percent*
Water bath alone	135 $K \cdot \rho$	100
Water bath + 20-cc tumor	150 $K \cdot \rho$	111
Water bath + 40-cc tumor	164 $K \cdot \rho$	122

Experiment 1

Solution with a concentration of radioiodine of 0.15 microcuries per cc was used in the flat phantom. Concentration in the 20 and 40-cc "tumors" was twice this value or 0.30 microcuries per cc. Tumors were placed with centers at 5 cm depth. See table below.

Accuracy of localizing the 40-cc tumor in the flat phantom was then demonstrated by taking counts toward the center of the tumor, and at varying distances from that position with the counter kept parallel to its original position. Tumor diameter was 4.3 cm.

	Cpm		*Percent*	
	Calculated	*Measured*	*Calculated*	*Measured*
Water bath + 40-cc tumor	1,450	1,351	100	100
Water bath + 20-cc tumor	1,600	1,457	111	108
Water bath	1,740	1,605	122	118.5

Displacement from center position	*Cpm*
Center	116% (compared to counting rate without "tumor" = 100%)
2 cm from center	114%
3 cm	106%
4 cm	101%
5 cm	96%

This experiment with the flat phantom seemed to confirm the belief that a 40-cc tumor (or tumor plus edema) could be detected. A 20-cc (or less) tumor unaccompanied by edema may not be detected because of the possible 10% error in biological experiments. Any conclusions on possibility of tumor detection depend, of course, on the ratio of concentration of dye in the tumor area to that of normal brain, here assumed to be 2:1. This failure to detect very small tumors has been confirmed in a few operated cases.

Experiment 2

A calvarium was filled with iodide solution to a depth of 6 cm. It was expected that the total counts would be lower than with the flat phantom or the complete skull (in which the full 10-cm depth of solution is present) while tumor counts would remain the same, giving a false increase in counting rate when the tumor was added.

Concentration of I^{131} was 0.45 microcuries per cc of solution. Background counting rate with the counter below and normal to the midportion of the calvarium was 3,058 cpm. Addition of the 40-cc "tumor" at 5-cm depth, increased the rate to 3,993 cpm. Increase due to tumor is, therefore, 30%. With full depth of active material in the skull, the background rate would be greater, reducing the increase due to the tumor to the expected 20%.

This experiment seems to confirm in a skull experiment the findings with the flat dish phantom.

Experiment 3

A check was required on the symmetry conditions specified by Moore in his counting technique on brain patients. A calvarium was filled with iodide solution containing 0.24 microcuries per cc. A left frontal tumor 40 cc in volume was inserted equidistant (4 cm) from the temporal and frontal surfaces. Here again, the increase in counting rate due to the tumor is falsely high because of the limited depth of the solution in the calvarium. The numbers marked (*) would be most affected by the increased depth of active material in the complete skull.

	Cpm	*Percentage increase on side of "tumor"*
Forehead	Right 2,015 Left 2,512	25%
Frontal, 45 deg	Right 1,699* Left 2,489	46%
Frontal, Midline (just includes tumor)	Right 1,820 Left 2,100	15%
Earline, 45 deg	Right 1,690 Left 1,836	8%

A 20-cc "tumor" (left frontal) was inserted in this same phantom. Counting rates observed were:

Forehead	Right 1,716 Left 2,121	24%
Lateral frontal, 45 deg (counter directed to miss tumor)	Right 1,620 Left 1,678	3%
Midline frontal	1,680	
Midline earline	1,698	
Lateral frontal (counter directed toward tumor)	Right 1,376* Left 1,602	17%

This experiment seems to bear out Moore's contention that the simplest method of surveying the head is this method of symmetrical positions.

Experiment 4

The question has been raised whether the counter should be maintained normal to the skull or whether a rectangular system of coordinates is preferred. The results which follow indicate clearly that the method of keeping the counter normal to the skull is more reliable. A 40-cc "tumor" was placed in the center of the calvarium. The solution contained 0.45 microcuries per cc.

Lateral displacement from center	*Counter normal to skull*	*Counter parallel to center position*
0	4,000	4,000
2 cm	4,072	
3 cm	3,399	3,316
5 cm	3,168	2,686
Base level, (no tumor) counter at center of calvarium.	3,058	

Value of Total Counting Rate

Total counting rate in Experiment 1 was 9,000 cpm per microcurie per cc of solution. Depth of solution was 10 cm. In Experiment 2 with a depth of solution of 6 cm, the counting rate was 6,800 cpm per microcurie per cc. For 10-cm depth, this would increase to about the expected 9,000 counts per minute. In Experiment 3, the total rate was about 8,500 cpm per microcurie per cc for the forehead, and only 7,100 for the fields affected by the limited depth. It may be that the total counting rate may have value in itself in diagnosis of brain conditions.

Radiation to Brain

Counting rates reported by Moore* are of the order of 150 to 300 cpm. This indicates (if we accept the figure 9,000 cpm per microcurie per cc or gram) a concentration of I^{131} of less than 0.04 microcuries per gram. The radiation intensity then would be less than 20 mrep per hour. This will not be of consequence as a radiation hazard. The dye is not retained for a long period of time.

Summary

Data are presented from four experiments with water phantoms containing radioactive iodine. Calculations are presented on the idealized flat phantom which are well checked by the experimental data. Conclusions which can reasonably be drawn are:

1. Brain tumors which retain a concentration of radioactive diiodofluorescein twice that of the surrounding brain tissue (shown to be the case in biopsy material) can be detected with the Geiger counter provided that the tumor volume exceeds 20 cc and approaches 40 cc. Greater concentration ratios of the dye will permit detection of smaller tumors.

2. Total counts taken must be adequate to lower the statistical fluctuation in the counting rate to a fraction of the 15 to 20% increase in count expected due to the tumor.

3. The method of symmetrical counting positions used by Moore proved adequate in the phantom experiment. Maintaining the counter normal to the skull seems to be the best procedure.

4. Use of a defining cone or the method of taking counts with or without a lead mask gives equally good results. A tapered cone is not of value.

* * *

The authors wish to express their appreciation to Dr. K. W. Stenstrom, Professor of the Department of Biophysics, for much helpful advice.

* G. E. Moore. Use of Radioactive Diiodofluorescein in the Diagnosis and Localization of Brain Tumors, *Science* **107**, 569 (1948)

Chemical Process Industries and Nuclear Energy

THE FUNCTION OF CHEMICAL PROCESS INDUSTRIES is to take raw materials of low-use value and put them, by physical and chemical changes, into forms where the use value is higher. The physical changes are classified as "unit operations" (such as heat transfer and the separation of materials), and the chemical changes are classified as "unit processes" (such as polymerization and oxidation). Unit operations and unit processes are carried out in either a continuous manner or in a batch manner, as well as in combination. Characteristic of chemical industries is the fact that products other than those primarily desired are often obtained as "byproducts."

Industrial concerns in the United States have built up a large number of development organizations which are highly skilled in chemical process work and whose engineers today do the bulk of such work for the world. The process chemical engineers of these firms utilize the older batch-type process, similar, in all respects, to the cook's operations in getting the family dinner, and also the more modern and efficient continuous-type process, perhaps best exemplified by the water filtration plant of a modern city.

From a chemical engineering standpoint, the fission reaction in a nuclear reactor represents a single unit process. The complete nuclear energy plant is thought of as a continuous sequence of such standard unit processes and unit operations as reaction, heat transfer, materials separation, and materials movement. In operation, the economics of a nuclear energy plant would be similar to that of a combined continuous flow power plant and an oil refinery. The pure fissionable material produced as a byproduct by a breeder reactor, for example, would be marketable as a valuable fuel, along with other byproducts, such as tracer isotopes and secondary gamma-ray sources.

The production of fissionable material from uranium ores is thus seen to have the essential technical and economic features of a chemical process industry. From the mining and refining of raw ores to their conversion to fissionable material in isotope separation plants and breeder reactors, we find that the research, engineering, and administrative problems call for much the same technical methods and business organization that are found in the rubber, heavy chemicals, petroleum and other process industries.

The design and construction of a nuclear energy plant for low-cost operation will require the same kind of process development that was necessary to bring, say, catalytic cracking from the laboratory stage to successful commercial production. The development of the fluid catalytic process is an illuminating

example of the work of the process chemical engineer in applying the principles of the continuous flow process to the problem of increasing our supply of aviation gasoline, just prior to our entry into World War II. The fluid catalytic process was at much the same stage of development during the period 1938 to 1940 as the atomic energy field is today. That is, the principles of catalytic cracking and reforming were known, the scientists had completed their work, and the system required integrated continuous processing and the development of modern engineering methods to produce the successful unit.

As is usually the case under stress, research and development were carried along concurrently with engineering, and the result was that over twenty-six major fluid catalytic refining units were designed, constructed and placed into operation in adequate time to meet the astronomical demands for aviation gasoline. Simultaneously, the units were designed to produce as a principal byproduct, a butane-butene stream, which was further catalytically reformed to Butadiene, and these units supplied approximately 600,000 tons per year of the Butadiene for the Buna-S-Rubber program. The process was so integrated and controlled as a continuous process that the more and better grade aviation gasoline made, the more and better grade Butadiene was obtainable.

The ultimate function of nuclear energy, however, is not at all obvious. It may even be that only single-purpose reactors are of any use, designed to produce power or fissionable material but not both. Or on the other hand, the simultaneous production of power and fissionable material may be the most economic possibility. The economic balance will have to be determined competitively through the interplay of many branches of engineering and industry.

In addition to the process chemical engineers who will carry out the development engineering and construction program for nuclear energy, another group of engineers, associated with the ultimate consumer, should be called on. The real industrial customer would appear at present to be the private power utility companies, and their engineers also should now be active in determining development trends. The only way at present to make the possibility of nuclear energy real to industrial customers is to make it possible for them to study the economics themselves, with full access to all pertinent information. Instead of sponsoring expensive overstaffed reactor development projects to build any kind of reactor from which power may be squeezed, we should capitalize on the wealth of experience available in industry to give economic balance and direction to the programs.

For a comparatively small amount of money it would be possible to obtain competent paper studies of the main schemes for nuclear power development, which would show exactly what the industrial potential is. The present AEC has made relatively small use of this valuable device. With the exception of the brief study which formed the basis of the Baruch report to the United Nations, no such study is available. The Fourth Semi-Annual Report of the Atomic Energy Commission devoted approximately three pages to nuclear energy economics with no conclusions whatever. The chemical process industry, on the other hand, leans heavily on this type of economic study to

guide their research and development. In any large development, the design and experimental work is piloted by scores of paper studies, which are constantly being brought up to date.

The practical and rapid development of nuclear energy plants along lines which show economic promise clearly requires more than the expenditure of large sums for research by physicists, basic chemists, mathematicians and other types of scientists. The scientists have already opened up the nuclear-chemical process industry in a very practical way. Some experienced process engineers have already assayed the problem of nuclear reactor plants, and, assuming the availability of a customer, are fully prepared to design specific plants within a reasonably short time. Basic process design can proceed concurrently with applied research and equipment development, and if started now, would unquestionably shorten by many years the time required for the commercial operation of a large-scale nuclear energy plant, operating as a continuous and wholly integrated unit.

All the raw materials, skills, and experience for a great, new process industry are now at hand, and it will be surprising if the energies seeking its development are not soon set free.

—*Walter M. DeCew*

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108	R.F. High Voltage Power Supply (voltage doubler type) (*c.d.*)	.05
109	R.F. Coil for R.F. High Voltage Power Supply (voltage doubler type) (*c.d.*)	.05
111	Pulse Analyzer — 1 Channel (*c.d.*)	.15
113	Scale of 64 with R.F. Power Supply Model 400 (*c.d.*)	.15
128	Counting Rate Meter—Model 200 (*c.d.*)	.15
131	Model 100 Amplifier (*c.d.*)	.15
132	Model 100 Precision Pulser (*c.d.*)	.15
135	Amplifier, Preamplifier (*c.d.*)	.15
136	Discriminator—Pulse Generator (*1 p*)	.05
242	Instrumentation of the Hanford Engineer Works	.10
245	Alpha Chamber Modified (*9 dwgs*)	1.00
246	Revised Alpha Chamber (*16 dwgs*)	.80
341	Integrating Polonium Meter (*6 pp*)	.05
346	Differential Pressure Indicator (*47 pp*)	.25
417	Complete Blueprints for duPont Carbon Fluorine Cell, Blueprints Comprising Assembly Drawing DW-5175, Detail Drawings DWD-5673; DWD-5682, DWD-5687; DWD-5760; DWD-5812; DWD-5813; DWD-5814; DWD-5976; Sketches DWS-3799; DWS-3800; DWD-3862; and DWS-3863. (*18 dwgs*)	1.10
522	Instruction-Leak Detector, Cat. No. 69339-0G3 (*59 pp*)	.25
533	Electronic Circuits—V (*10 pp*)	.10
535	A Simple Carbon Dioxide Vapor Pressure Thermometer (*5 pp*)	.05
558	Discriminator for Photographic Analyzer. (*c.d.*)	.15
562	The Ryerson Electrometer. (*1 pp*)	.05
705	Alpha Hand Counter Mark 10 Model 10A (*2 pp*)	$.05
725	The Use of Hearing Aid Type Tubes in Portable Counting-Rate Meters and Amplifiers. (*10 pp*)	.10
739	Electronic Circuits—11 (*38 pp*)	.30
778	A 160/1500 Volt Regulated Power Supply	.10
826	Power Supply	.05
827	Pulse Unit Model 1	.15
828	300 Mc Transmitter Pulser (mock-up)	.15
829	Video Amplifier and Scope	.15
882	Alpha Air Monitoring System. (*2 pp*)	.05
884	An Integration Radiation Meter for Beta and Gamma Rays, Sigmion Mark 10, Model 70. (*2 pp*)	.05
885	Quartz Fiber Microbalance (*3 pp*)	.05
886	Ryerson Pocket Meter (*4 pp*)	.05
894	Fast Amplifier Circuit Schematic	.15
895	Model 300 Sweep (*c.d.*)	.25
900	30 KV Power Supply	.05
902	Geiger Counter Radiation Meter (*6 pp*)	.10
908	Model L. A.—100 C.R. Oscilloscope (*c.d.*)	.15
913	Apparatus for Regulating Fluorine Flow (*1 p*)	.05
914	Electronic Circuits VI (*c.d.*)	.30
915	Test Unit Power Supply	.15
919	Dynamics of a Mass of Hot Gas Rising in Air (*13 pp*)	.10
920	Battery Operated Field Pulser	.05
921	Calibrated Sweep Generator (*c.d.*)	.15
923	Fast Sweep and Scope (*c.d.*)	.15
924	1500 Microsecond Delay Unit (*c.d.*)	.15
925	Four Channel Line Driver (*c.d.*)	.15
926	High Voltage C.R.O. (*2 dwgs*)	.30
927	Model Six Sweep (*c.d.*)	.15
929	Regulated Power Supply 450 V., 300 V. and 150 V. for Fast Sweep Chassis	.15
930	Saw Tooth Generator and Discriminators	.15
931	Three Channel Mixer	.05
932	Camera Synchronizer	.15
942	Eight Inch Vacuum Pump (*6 dwgs*)	1.15
943	Four Inch Oil Diffusion Pump (*10 dwgs*)	.75
952	Description of and Instruction for Operation and Maintenance of a New Model Gamma Ray Pocket Survey Meter (*10 pp*)	.10
960	Six Inch Diffusion Pump (*5 dwgs*)	.60
961	Four Inch Pump Valve (*3 dwgs*)	.30
980	Cloud Chamber Tank Assembly	.15

MDDC	Title	Price
997	Cutie Pie. A Portable Radiation Instrument (*10 pp*)	$.10
1057	Portable Probe Type Ionization Meter (*5 pp*)	.05
1112	Spiral Carrier (*c.d.*)	.15
1157	Portable Alpha Survey Meter, Mark 1 Model 41A, (*3 pp*)	.05
1191	Drawing No. 2W1693C; "Z" Regulator Main Power Amplifier Schematic (*c.d.*)	.15
1192	Drawing No. 2W1893B; "Z" Regulator Control and Pre-Amplifier, Schematic (*c.d.*)	.15
1265	Rotary Seal. Four Drawings (*5 dwgs*)	.90
1293	Remote Control Pipette. Prints D2117, D2118, D2119, D2120, E2020 (*5 dwgs*)	1.40
1484	A Portable Microroentgen Meter (*10 pp*)	.10
1552	Rotary Leaf Filter (*2 pp*)	.05
1598	Oscilloscope Camera Self Supporting (*9 dwgs*)	2.45
1602	Electric Time-Switch for Closing Circuits at Accurately Regular Intervals	.10
1652	Low Pressure Alpha Counter (*2 pp*)	.05
1766	Operation and Service Notes on Batteryless Type A Counting System Using Parallel Plate or Concentric Cylinder Chamber (*6 pp*)	.05

Metallurgy and Ceramics

94	Room Temperature Casting Resin for Mounting Metallographic Specimens. (*5 pp*)	.05
296	Hot Wire Reduction of Metals (*8 pp*)	.05
526	Martempering of K-46 Tool and Die Steel (*9 pp*)	.10
539	Metallurgy in the Development of Atomic Power (*20 pp*)	.10
728	Preparation of Compacts of High Density Uranium Hydride (*4 pp*)	.05
1166	Use of Redux Adhesives for Bonding Metal (*2 pp*)	.05
1800	The Preparation of Very Thin Plastic Films (*3 pp*)	.05

Physics

143	Excitation of Plasma Oscillations	.05
149	Energy of Neutrons from MsTh-D, La-D, Y-Be, and Sb-Be Photo-Neutron Sources (*9 pp*)	.10
155	Description of a Frequency Modulated Cyclotron and a Discussion of Deflector Problem	.05
157	Frequency Modulation for Berkeley 37" Cyclotron	.10
171	Isotopic Absorption of Slow Neutron in Cadmium	$.10
173	Measurement of Electric Field Strength in a Cavity Resonant at 200 mc	.05
174	A Method for Measuring Small Changes in Alternating Magnetic Fields	.05
182	The Nuclear Reaction (p,pn)	.05
184	Isotope Chart	.30
201	Distribution of Neutrons in the Atmosphere	.05
205	Angular Distribution of n-d Scattering for 2.5 Mev Neutrons	.10
206	Measurement of the Cross-Section for Reaction $d(d,n)He^3$	.10
207	Measurement of the Cross-Section for the Reaction $d(d,p)H^3$	.10
210	Neutron Spectroscopy	.10
222	Control Equipment for 2.5 Mev Van der Graaff Giving an Ion Beam Constant to ± 1.5 kev	.05
223	Nomographic Charts for Nuclear Reactions (*7 charts*)	1.25
293	Sweeping of Radioactive Gases from a Homogeneous Pile (*14 pp*)	.10
327	A Bent Crystal Neutron Spectrometer and the Cross Sections of Cadmium and Iridium	.10
353	Evaluation of Scattering Data (*42 pp*)	.15
362	Neutron Absorption Method for Boron Analysis (*5 pp*)	.05
378	Elementary Pile Theory	.15
385	Measurement of Neutron Fluxes in the Region 30 to 500 Kev with Proportional Counters (*10 pp*)	.10
387	The Counting Method of Isotopic Analysis of Uranium (Parts 1 and 11) (*62*)*pp*	.25
414	Absolute Calibration of a Ra-Be Neutron Source (*54 pp*)	.25
447	Ionization Chamber and Electronic Equipment for the Observation of the Shape of the Microsecond X-Ray Pulses (*10 pp*)	.10
448	Time of Collection of Electrons in Ionization Chambers	.10
458	Operation of Proportional Counters at Pressures Above Atmospheric	.10
472	Po Alphas as BF_3 as a Neutron Source (*14 pp*)	.05
473	High Frequency Insulator and Vacuum Gap Breakdown Tests (*15 pp*)	.10
475	Theory of Ion Chambers	.10
517	Formation of Focussed Space-Charge Limited Electrons and Ion Beams (*18 pp*)	.10
520	Abnormal Isotope Abundance Produced by Neutron Absorption in Cadmium	.05

MDDC	Title	Price
586	Formation of Focussed Space-Charge Limited Electron and Ion Beams. Part II. Design of Electrodes. (*46 pp*)	$.20
702	Boundary Conditions at Interface Between Medium and Vacuum; The Extrapolation Distance (*14 pp*)	.10
734	A Slide Rule for Activation and Decay Calculations (*5 pp*)	.05
745	Stability of a Fin in Boiling Liquid (*7 pp*)	.05
780	Table of Legendre Polynomials P_n (cos θ) for N = 0 (1) 20, and θ = 0° (1) 180° to Six Deci mals. (*8 pp*)	.10
863	Film Prog. 39. Film Prog. 18. Film Prog. 41 (*3 pp*)	.05
864	New Observations on Two-Dimensional Condensation Phenomena	.10
890	Neutrons Monitoring by Means of "Special Fine-Grain Alpha-Emulsion" Film (*8 pp*)	.10
917	Time for Emission of Fission Neutrons (*23 pp*)	.15
959	Energy of Fission Fragments of U^{233}, U^{235}, Pu^{239} (*1 p*)	.05
964	"184" Cyclotron Oscillator Capacitance Measurements (*3 dwgs*)	.05
969	184" Cyclotron Pumping Speed Test (*2 pp*)	.05
982	184" Cyclotron-Radiation Measurement of Breech Load Probe Head (*3 pp*)	.05
983	The University of California Synchrocyclotrons (*14 pp*)	.10
986	Frequency Modulated Cyclotron Characteristics (*5 pp*)	.05
990	Heat Transfer in Sphere Beds (*16 pp*)	.10
1014	Course in Nuclear Physics for Engineers (*151 pp*)	.50
1028	184" Cyclotron Half-Life Measurements on Dee (*2 pp*)	.05
1032	Pulsed Deflector for 184" Frequency Modulated Cyclotron (*14 pp*)	.10
1051	184" Cyclotron Vertical D.C. Electrostatic Deflector (*2 pp*)	.05
1069	Artificial Radioactive Isotopes of Polonium, Bismuth and Lead Chapter IV. A New Reaction with High Energy Deuterons (*6 pp*)	.10
1073	Thermal Neutron Flux in the Argonne Heavy-Water Pile (*1 p*)	.05
1077	Stars in Photographic Emulsions Produced by Particles Accelerated by the Cyclotron	.10
1090	Cloud Chamber Study of the Particles in the Neutron Beam of the 184" Cyclotron	.10
1092	Some Operating Phenomena Associated with the 184-inch Cyclotron	.05
1118	Report No. EC-11, Dated September 15, 1944. I. Standard Threshold Test. II. Program for "Bent Cathode Test" as a Means of Determining Impurities in Nickel Baths (*24 pp*)	$.15
1175	Lecture Series on Nuclear Physics (Lectures 1 through 46) (*152 pp*)	.55
1226	The Physical Principles and Techniques of Auto-radiographs	.10
1304	Some Engineering and Economic Aspects of Nuclear Energy (*10 pp*)	.10
1340	Deposition of Pure Boron. III. A Flow Method for the Deposition of Boron on Iron Cylinder (*10 pp*)	.10
1415	Cross Section of Powdered Graphite-Orientation in Graphite by X-Ray Diffraction-Cross Section and Crystal Orientation in Aluminum. (*8 pp*)	.10
1436	Preliminary Comparison of Radon-Boron and Radium-Beryllium Neutron Sources (*2 pp*)	.05
1437	Neutron Distribution in Paraffin (*2 pp*)	.05
1628	Heat Transfer in Film Boiling from Horizontal Tube	.15
1669	Laue Photography of Neutron Diffraction	.05
1686	The Beta and Gamma Spectra of Ga^{72}	.05

Abstracts of Declassified Documents

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Miscellaneous

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NUCLEONIC EVENTS

POWER LAG PRODUCES AEC REORGANIZATION

The following article on the reorganization of the Atomic Energy Commission was written on August 25 by Robert Colborn of the McGraw-Hill Washington Bureau.

The Atomic Energy Commission is getting its first major shake-up since the atomic energy program was put in civilian hands a year and a half ago. With a minimum of publicity, these things are being done:

1. The lagging power development program is being reorganized, centralized, "beefed up."

2. AEC relations with the military atomic power projects—Nuclear Energy for the Propulsion of Aircraft (NEPA) and Nuclear Energy for the Propulsion of Ships (NEPS)—are being straightened out. This has already precipitated a rather bitter fight with the Navy.

3. The agency's whole organization chart is being revamped, with new lines of authority.

4. Many of AEC's top administrative people are on their way out.

Why are these changes being made now? Partly, of course, it's the normal reshuffle to be expected when a new agency has had time to shake down. More significantly, it's a process of clearing the decks for next January's expected encounter with a Dewey administration. The commissioners are in office until June, 1950, but they will have to get along with an administration inclined to skepticism about a holdover agency.

In addition, the move seems to have been precipitated by increasingly vigorous criticism of AEC's rather lackadaisical attitude toward power development. The criticism comes from two sources: the military, who feel they have had little or no cooperation from AEC in developing atomic engines for aircraft and ships; the commission's Industry Advisory Committee, which has just completed a thorough examination of AEC operations and is now drafting a final report.

The personnel changes are drastic, and start at the general manager's office. All that has been announced is the appointment of a new deputy manager—Carleton Shugg, who has been in charge of the huge Hanford Plutonium plant. Actually, Shugg will take over nearly all of General Manager Carroll Wilson's administrative duties. This is supposed to free Wilson for ivory-tower policy thinking; however, observers familiar with Washington's "kick-em-upstairs" technique are assuming that Wilson will soon be looking for another job.

Shugg is one of the ablest of the AEC's field managers. He's an Annapolis graduate, was active in the Navy's submarine development program in the twenties, went into business as a small electrical equipment manufacturer, during the war built and managed Cramp and Todd shipyards.

At the next level down, the AEC divisions are being completely revamped. Of the five operating division heads, only two look likely to survive the reorganization.

Shields Warren's biology and medicine division is collapsed into James Fisk's research division. Fisk himself will be leaving AEC shortly. (Ed. Note: On August 27, Dr. Fisk resigned

to become professor of applied physics at Harvard University.)

John Gustafson's raw material division is similarly to be collapsed into Walter Williams' production division.

The divisions themselves get a new role. Previously they were simply staff organizations; the five AEC field offices reported directly to the general manager.

Now Williams' enlarged production division takes direct operating charge of the job of turning out fissionable material. Hanford, Oak Ridge, and the New York raw material procurement office will all report directly to him.

To strengthen the power development program, the old engineering division is being converted into a reactor development division, with direct control over the Chicago Argonne Laboratory, where reactor work is now concentrated. The Knolls Atomic Power Laboratory at Schenectady apparently goes under Williams' control. However, in practice, this laboratory has concentrated more on development problems connected with the new plutonium plant at Hanford than on power work. Its future role is uncertain.

R. S. Warner, present head of the engineering division, is reported likely to be replaced by someone more familiar with the division's new job of reactor development.

This move is in line with recommendations of the Industry Advisory Committee. IAC feels that power development has been held back by the way AEC has spread the problem thinly throughout the organization.

The Los Alamos bomb development and assembly center will report to Gen. James McCormack's division of military applications.

AEC's relations with the Air Force's airplane engine project and the Navy's ship propulsion project are still being worked out. Last June, Secretary of Defense James Forrestal's Research and Development Board recommended that AEC give more help to these projects and work out a closer administrative connection with them.

MIT Studies Propulsion Projects

AEC's response to this proposal was to contract with Massachusetts Institute of Technology to study the feasibility of these propulsion projects, to review the work to date, and to advise on the next steps. MIT has put about 40 people to work on the job—a couple of faculty members, a corp of graduate students, and a few outside consultants —and is expected to report in the fall.

The first effect of this move, of course, has been to bring work on the Navy's NEPS nearly to a standstill. This project is still in an early stage, simply an informal contract with Westinghouse to make preliminary studies of possible atomic submarine engines. The Navy is infuriated by the delay. Last week a bitter letter went from the Bureau of Ships to AEC bluntly accusing the commission of lack of interest in NEPS, and of incompetence to handle it and asserting an intention to sever all connections with AEC. The Bureau of Ships is now trying to induce Forrestal to demand that AEC turn over the Knolls Power Laboratory to the Navy.

The NEPA is far enough along so that it hasn't been hurt as badly by the uncertainty involved in an investigation. NEPA has just received its first million dollars of Navy money to add to $11-million of Air Force funds, has arrived at a decision as to the type of engine and aircraft to work on, and expects to spend $100–150 millions over the next four or five years developing a workable engine.

For this reason, and because indications are that MIT will recommend continuance of NEPA, under the AAF, the Air Force hasn't got as het up as the Navy.

AEC ESTABLISHES PERSONNEL ADVISORY COMMITTEE

The Atomic Energy Commission has announced the establishment of a six-man advisory committee on personnel management to provide for a continuous review of AEC personnel practices. Members of the committee, which will be a permanent body, will meet monthly. They will visit from time to time the various AEC installations in all parts of the country to familiarize themselves directly with personnel management problems in connection with selection, training, labor relations, communications and morale of both AEC and contractor employees.

Members of the committee are: Arthur S. Flemming, president of Ohio Wesleyan University, chairman; Lawrence A. Appley, president of the American Management Association; Alvin E. Dodd, honorary president of the American Management Association; L. Clayton Hill, professor of industrial relations, University of Michigan; Wallace Sayre, professor of public administration, Cornell University; and Thomas G. Spates, vice president for personnel administration, General Foods Corporation.

STANFORD TO BUILD 1-BEV ELECTRON LINEAR ACCELERATOR

Stanford University will build a 1-Bev electron linear accelerator according to an announcement by Acting President Alvin C. Eurich. Development work, which will extend over a three-year period, will be financed under contract with the Office of Naval Research.

Construction work is under way on a building to house the projected 160-foot accelerator which William W. Hansen, director of the Stanford Microwave Laboratory, predicts will develop at least three times as much energy as the massive cyclotron at the University of California. A 12-foot pilot model of the accelerator, constructed by Dr. Hansen more than a year ago under an ONR contract, has already produced 6 Mev electrons.

OAK RIDGE TO CONTINUE ISOTOPE TECHNIQUE COURSES

The Oak Ridge Institute of Nuclear Studies has announced that four additional courses in the techniques of using radioisotopes have been scheduled for the fall and winter months. The additional courses are being offered in view of the fact that more than 300 qualified individuals applied for entrance to one of the three courses held during the summer months. There are only 96 places in these three courses.

Dates for the new courses and the fields of interest which will have priority are: industry, October 25; Government, January 3, 1949; medicine, February 14, 1949; and general, March 14, 1949.

Additional information and application blanks may be obtained from Ralph T. Overman, Head, Special Training Division, Oak Ridge Institute of Nuclear Studies, P. O. Box 117, Oak Ridge, Tennessee.

WESTINGHOUSE MEN TO WORK AT ARGONNE LABORATORY

A scientific "lend-lease" program, aimed at speeding all phases of atomic energy research, has been initiated between the Argonne National Laboratory, Chicago, and the Westinghouse Electric Corporation, according to a recent announcement by Walter H. Zinn, director of the Argonne Laboratory, and J. A. Hutcheson, director of Westinghouse Research Laboratories. According to arrangements, the Westinghouse Research Laboratories in East Pittsburgh, Pennsylvania, will make available to Argonne, at its request, specialists in any required field of research and engineering. The scientists

and engineers selected will be granted a leave of absence from their regular duties to work at Argonne. In full operation, the project should require the services of some twenty to thirty Westinghouse men. The first three men to undertake the new assignment are E. Bruce Ashcraft of the Research Laboratories, Adolph H. Toepfer, East Pittsburgh Works, and N. J. Palladino of the South Philadelphia Works.

U. S., CANADA, U. K. REVIEW DECLASSIFICATION GUIDE

In the interest of uniform application of measures for security of atomic energy information, representatives of the atomic energy agencies of Canada, the United Kingdom, and the United States held their second meeting last month in England. Declassification guides previously developed were reviewed in the light of technical developments during the past ten months.

Representing the three nations were: United Kingdom—J. D. Cockcroft, H. J. Emeleus, K. Fuchs, R. E. Peierls, and J. H. Awbery; United States—W. C. Johnson, W. F. Libby, J. H. Manley, R. L. Thornton, F. de Hoffmann, H. A. Fidler, and Bennett Boskey; and Canada—W. B. Lewis and L. G. Cook.

PROMINENT SCIENTISTS TO AID NEW NUCLEAR COMPANY

Four scientists, prominent in the field of nuclear energy, have been named as advisers to Nuclear Development Associates, Inc., a corporation recently formed to engage in the scientific and engineering development of nuclear energy. The four are Charles D. Coryell, Bernard T. Feld, Lothar W. Nordheim and Frederick Seitz. Eugene P. Wigner is also an adviser to NDA.

Elected to the Board of Directors are Gale Young, technical director; John R. Menke, president; Francis L. Friedman and Gerald Goertzel.

CRANE CO. TO SUPPORT U. OF CHICAGO RESEARCH

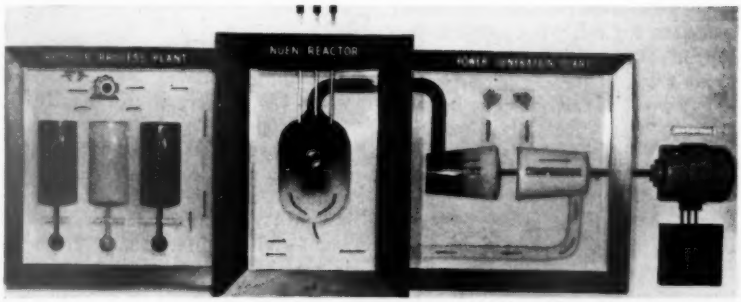
A $150,000 contribution to the University of Chicago's basic research program has been made by the Crane Company, according to an announcement by John L. Holloway, president of the company. The amount covers both a five-year industrial membership in the university's Institute of Metals, and a fellowship in its Institute for Nuclear Studies.

Crane brought to fourteen the number of industrial organizations supporting the university's basic research program being carried on in the Institutes of Metals, Nuclear Studies, and Radiobiology and Biophysics. Other industrial members are: Westinghouse Electric Manufacturing Co., U. S. Steel Corp., Standard Oil Co. of Indiana, Aluminum Co. of America, Beech-Nut Packing Co., Standard Oil Development Co. of New Jersey, Pittsburgh Plate Glass Co., Shell Oil Co., Inland Steel Co., Sun Oil Co., Celanese Corp. of America, Commonwealth Edison Group, and Bethlehem Steel Co.

INDIA ESTABLISHES ATOMIC ENERGY COMMISSION

An atomic energy commission has been set up by the Indian government to work directly under Prime Minister Nehru with a three-fold assignment. It is: to protect the interests of the country with regard to utilization of atomic energy resources, to survey all sources of such raw materials in India, and to promote research in a laboratory of its own and subsidize similar work in others.

Chairman of the commission is Homi J. Bhabha, director of the Tata Institute of Fundamental Research. Others are K. S. Krishnan and S. S. Bhatnagar.



(*Above*) **Close-up view of NUEN plant. In foreground is reactor building, with processing structure behind it and power unit at the rear.** (*Below*) **Schematic view of plant showing incorporation of three processes into one integrated unit. Illustrated are: (1) the Reaction Section (center) where fission takes place in a reactor and creates the heat used to develop power, (2) the Turbine-Generator Section (right) which converts the heat into electrical power, and (3) the Recycle Process Section (left) which purifies the fuel already used making it available for reuse, and separates out the byproducts**

KELLEX CORPORATION EXHIBITS MODEL OF INTEGRATED NUCLEAR ENERGY POWER PLANT AS CENTER OF FUTURE INDUSTRIAL LIFE

A nuclear energy power plant which would utilize all of its fuel and would supply vital products to medical, agricultural and industrial research, and a wide range of industries, was depicted in an exhibit by the Kellex Corporation at the Golden Anniversary Exhibition of New York last month.

"The NUEN plant ('NUclear ENergy')," it was pointed out by A. L. Baker, executive vice president of the Kellex Corporation, "is projected with a view to developing an integrated continuous flow power plant which would meet the industrial needs and fit into the economy of the future America

. . . The most significant feature of the NUEN plant is the principle of integration which dominates its design and which has been adhered to fully in developing the exhibit.

"We refer to it as a NUEN plant to stress the point that it should be considered not simply as an atomic power plant. Actually it would be far more. It would be a plant that, while generating power, continuously freshens and purifies its own fuel stream and this in itself would be one of the revolutionary new contributions of atomic power and obviously of great importance economically."

"This processing," he said, "would be accomplished by separating out fission products and excess fissionable materials. These byproducts have a multitude of uses in the nuclear program in research, industry and in medicine."

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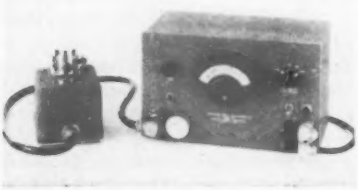
PRODUCTS and MATERIALS

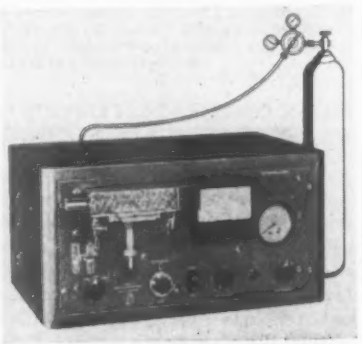
VIBRATING REED ELECTROMETER

Applied Physics Corp., 30 W. Green St., Pasadena 2, Calif. The Model 30 unit, capable of measuring d-c currents as small as 1×10^{-17} amperes, consists of two parts, the electrometer head and the amplifier cabinet, which are joined by a cable 4 ft long. The electrometer head is 5¼ in. × 6 in. × 7 in. high. The amplifier cabinet is 14¼ in. wide, 8¾ in. high × 8 in. deep. The shipping weight of the two units totals 90 pounds. A microammeter with a 4-in. scale is mounted on the control panel for indicating the charge on the electrometer. Four ranges are provided, corresponding to 10, 1.0, 0.1, and 0.01 micromicrocoulombs full scale. The instrument is not absolute, and special calibration is required if absolute measurements are to be made. The electrometer operates from the 115-volt, 50 or 60-cycle mains and consumes 50 watts.



ALPHA COUNTER

Nuclear Instrument and Chemical Corp., 223 W. Erie St., Chicago 10, Ill. The Model 117 alpha proportional counter system was designed for counting alpha particles in the presence of a strong beta activity. The unit consists of (1) a methane flow proportional counter with sample holder, (2) a built-in variable high-gain linear amplifier, (3) scale of 256 to 1, (4) built-in high-speed impulse recorder, and (5) variable high voltage supply. The complete



unit is constructed on a single chassis and housed in a steel enameled cabinet.

PROBE COUNTER

Radiation Counter Laboratories, Inc., 1844 W. 21 St., Chicago 8, Ill. This thin-wall probe counter has been developed for inserting into small recesses or into regions of high flux density. The diameter is 7 mm and the thin wall section 15 mm. The gas volume ex-

tends up the handle of the counter and a tubulation permits easy refilling. The instrument is the Mark 1, Model 100.

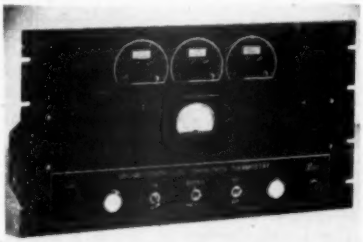
PORTABLE VAN DE GRAAFF

High Voltage Engineering Corp., 7 University Rd., Cambridge, Mass. Utilizing the well-known moving-belt and corona-spray principle of the

2,000,000-volt electrostatic units used in nuclear research and precision radiography, this smaller Van de Graaff generator develops 250,000 volts, positive or negative. Voltage output is adjusted by corona loading. A voltmeter reads terminal voltage directly and a polarity reversing switch permits selection of either positive or negative voltage. The entire apparatus weighs 150 pounds. It is 36 inches high with a base 21½ by 14 inches. The generator, with which no protective devices need be used, will operate from any 115-volt, 60-cycle, single-phase circuit fused for 20 amperes.

TEMPERATURE CONTROL

Spencer-Kennedy Laboratories, Inc., 10 Follen St., Cambridge 38, Mass. The model 400A bridge-controlled thyratron thermostat is a precision electronic temperature control, designed for use with furnaces, molds, chemical



baths, ovens and other devices which can be heated from 110-volt or 220-volt a-c lines. It is claimed that, with a properly designed heating unit, temperatures from 20° C to 1200° C can be maintained with an accuracy of ±0.5° C using heater resistance control; with a resistance thermometer, accuracy of control is said to be better than ±0.1° F from room temperature to 1200° F.

ULTRA-HIGH RESISTANCES

Vacuum-inclosed, evaporated platinum-on-glass resistors for use with

photoelectric cells and electrometers, and for other applications requiring resistance values between 10^6–10^{12} ohms, have been developed and patented by D. Vodar, Laboratoire de Physique Enseignement, Sorbonne, Paris. The commercial production and sale of the resistors has been undertaken by **Etablissement Beaudouin, 3 rue Rataud, Paris.** The advantages claimed for these resistances are that they obey Ohm's law within about 1% from 0.1 volt to 300 volts, are stable with time to within a few percent, are unaffected by humidity, and the magnitude of noise produced in the resistor is equal to the theoretically expected value for the temperature concerned. They are small in size, being about 2 inches long by ¼ inch in diameter.

DU PONT MAKES TITANIUM

The Du Pont Company has announced that it has begun the small scale manufacture of titanium metal, a new basic raw material for industrial development.

A pilot unit of 100 pounds daily capacity has been successfully placed in operation at the Newport, Del., plant of the Pigments Department. This, so far as the company knows, is the first time ductile titanium metal has been produced for commercial exploration. The U. S. Bureau of Mines has been producing the metal for research purposes.

Reports of the Bureau of Mines and other organizations indicate that the properties of titanium are such that it may be used for reciprocating mechanical parts and in jet engines where heat and pressure are great.

Most titanium metal which has been available heretofore has been in powder form. Du Pont is producing it now in sponge form and will shortly be producing ingots weighing up to 100 pounds. Running 99.5% plus of purity, the metal is ductile and can be rolled and drawn readily. It has high resistance to breaking or pulling and has high strength against distortion.

Present price of the Du Pont product is $5 per pound for quantities of 100 pounds or more in sponge form. Ingot prices will be set later. The company will supply small samples without charge to industrial and university laboratories for testing. As the process is improved and if demand warrants mass production of the new metal, the company hopes to be able to reduce the price sharply.

BOOKS

ADVANCES IN BIOLOGICAL AND MEDICAL PHYSICS, edited by J. H. Lawrence, and J. G. Hamilton, Academic Press, Inc., New York, 1948, Vol. 1, 484 p., $8.60. To be published yearly. Each volume will contain from eight to twelve articles surveying recent progress in radiation research, radiochemistry and tracer methods as applied to biology and medicine.

ATOMIC ENERGY, by Karl K. Darrow, John Wiley and Sons, Inc., New York 1948, 80 p., $2.00. A series of four lectures delivered by the author in 1947 at Northwestern University. Addressed to an audience of laymen, the material is a narrative of the basic facts which are pertinent to the field of atomic energy.

ABSTRACTS

CHEMICAL PUBLICATIONS

A study of the exchange of nickel in certain complex compounds using radioactive nickel, J. E. Johnson, N. F. Hall (Univ. of Wisconsin, Madison), *J. Am. Chem. Soc.* **70,** 2344–2348 (1948). The nickel exchange of ten nickel coordination compounds was studied using Ni^{63} as the tracer. The exchange data correlate well with predictions of bond type based on other evidence. Exchange was observed when the bonds were strongly covalent, while no exchange was observed for the ionic complexes. Special cases were noted.

The synthesis of phenanthrene-9-C^{14}, C. J. Collins (Oak Ridge Natl. Lab., Oak Ridge, Tenn.), *J. Am. Chem. Soc.* **70,** 2418–2420 (1948). Phenanthrene-9-C^{14} was synthesized in 50–55% yield (based on the $BaC^{14}O_3$) by the following steps: fluorene was converted to 9-fluorene-carboxylic acid-10-C^{14} (I) by carbonation of 9-fluorene sodium with $C^{14}O_2$; lithium aluminum hydride reduction of the methyl ester of I yielded 9-fluorene-methanol-10-C^{14}; dehydration of the latter with phosphorous pentoxide was accompanied by a Wagner rearrangement to form phenanthrene-9-C^{14}.

The reaction of some radioactive mustard-type vesicants with purified proteins, J. Wood, J. Rachele, C. Stevens, F. Carpenter, V. du Vigneaud (Dept. of Biochemistry, Cornell Univ. Medical College, New York), *J. Am. Chem. Soc.* **70,** 2547–2550 (1948). The synthesis of benzyl β-chloroethyl sulfide and n-butyl β-chloroethyl sulfide containing S^{35} from benzyl mercaptan and butyl mercaptan, respectively, are described. Crystalline insulin, pepsin and tobacco virus mosaic were treated with these radioactive vesicants. The reaction products differed from the original proteins in physical properties and had a higher sulfur content, indicating a chemical reaction between vesicant and protein.

Chemical studies on vesicant-treated proteins, F. Carpenter, J. Wood, C. Stevens, V. du Vigneaud (Dept. of Biochemistry, Cornell Univ. Medical College, New York), *J. Am. Chem. Soc.* **70,** 2551–2553 (1948). The preparations obtained by the treatment of insulin, pepsin and tobacco mosaic virus with benzyl β-chloroethyl sulfide and n-butyl β-chloroethyl sulfide containing S^{35} were further investigated by studying the alkali lability of the linkages formed between vesicant and protein. The rate of liberation of vesicant residues was dependent upon the temperature and the pH of treatment. By application of the washing-out technique to the radioactive material cleaved from vesicant-treated insulin, the cleavage product was found to be mainly the alkyl β-hydroxyethyl sulfide. Studies on vesicant-treated tobacco mosaic virus indicated that vesicant residues were attached to both the nucleic acid and the protein moieties of the virus.

Studies on acid hydrolysates of vesicant-treated insulin, C. Stevens, J. Wood, J. Rachele, V. du Vigneaud (Dept. of Biochemistry, Cornell Univ. Medical College, New York), *J. Am. Chem. Soc.* **70,** 2554–2556 (1948). A study of the acid hydrolysates of n-butyl β-chloroethyl sulfide-treated insulin provided evidence for the presence of N-(β-butylmercapto)-ethyl-phenylalanine. It is concluded that in the vesicant-treated insulin, a fraction of the vesicant had been attached to the free amino group of some of the phenylalanine moieties in the intact protein molecule.

The use of S^{35} in the measurement of transfer constants, C. Walling (U. S. Rubber Co., Passaic, N. J.), *J. Am. Chem. Soc.* **70,** 2561–2564 (1948). By comparison of the radioactivity of samples of polymer carried to different degrees of conversion in the presence of the same amount of S^{35}-containing mercaptan, the chain transfer constants of n-butyl mercaptan with styrene, methyl methacrylate, methyl acrylate and vinyl acetate were measured. The results indicate that ionic forms in the transition state may be important in determining reactivity in radical displacement reactions. A method for the synthesis of radioactive mercaptans from ZnS^{35} is described.

Exchange reactions between iodine atoms and organic iodides, R. M. Noyes (Columbia Univ., New York), *J. Am. Chem. Soc.* **70,** 2614 (1948). Comparative approximate rate constants for the exchange of atomic iodine with the iodine in allyl iodide, trans-diiodoethylene, iodobenzene, and ethyl iodide are much greater than 200, 1.0, 0.002, and less than 0.001, respectively.

Metastable transitions in mass spectra of 56 hydrocarbons, E. G. Bloom, F. L. Mohler, J. H. Lengel, C. E. Wise (Natl. Bur. Standards, Washington, D. C.), *J. Res. Natl. Bur. Standards* **39,** 437–442 (1948). The 362 metastable transitions observed in 55 compounds involve 32 different transitions involving loss of mass 2, 15, 16, 26, 27, 28, 29, 30, 42, and 44, or H_2, CH_2, CH_4, C_2H_2, C_2H_3, C_2H_4, C_2H_5, C_2H_6, C_3H_4 and C_3H_5. The great variety of metastable transitions show that molecule ions may dissociate step by step (in all cases where the initial ion is not the parent ion) or by losing a rather large mass from the parent ion. The intensity of the metastable transition depends on the intensity of the initial and final ion peaks.

Reported activity of osmium, A. H. W. Aten, Jr. (Inst. for Nuclear Research, Amsterdam), *Nature* **161,** 1019 (1948). A previous report has indicated *K*-electron capture in Os^{187} with a half-life of about 3×10^8 years. Author points out that osmiridium ores about 2×10^8 years old contain 30 to 50% osmium of which 1.64% is Os^{187}, whereas a half-life of 3×10^8 years would lead to a rhenium content of ¼%. If *K*-electron capture occurs in osmium, the half-life must be several orders of magnitude longer than reported.

X-radiation from a 20-Mev betatron, W. Bosley, J. Craggs, W. Nash, R. Payne (Metropolitan-Vickers Electrical Co., Manchester), *Nature* **161,** 1022–1023 (1948). The study of electron-positron pairs produced in a thin lead sheet in a Wilson chamber, and the study of the protons liberated in the photodisintegration of deuterons using deuterium-loaded plates, were used to obtain the spectrum of the radiation from a 20-Mev betatron. A large percentage of the radiation was of less than 5 Mev energy. The distributions obtained by both methods were in good agreement.

Processing thick emulsions for nuclear research, C. C. Dilworth, G. P. S. Occhialini, R. M. Payne (Bristol University, England), *Nature* **162,** 102–103 (1948). A nearly uniform development of emulsions 300μ thick may be achieved by the following procedure: The plates are soaked in water and then in cold developer; the temperature is next raised and after a suitable period of development further action is checked by a cold stop bath; the fixing is begun in a cold solution, the temperature of which is afterwards raised. Photomicrographs show proton tracks of nearly equal grain density at different depths in an emulsion 300 μ thick. The limit to the use of very thick emulsions is now set by optical rather than processing difficulties.

. . . I. W. RUDERMAN

LIFE SCIENCE PUBLICATIONS

Tissue localization and excretion routes of radioactive dibromestrone, G. Twombly, L. McClintock, M. Engelman (Dept. of Cancer Research, Columbia Univ., New York), *Am. J. Obstet. Gynecol.* **56,** 260–268 (1948). Dibromestrone labeled with radiobromine was prepared by brominating equilin. Dibromestrone is not localized selectively in the adrenals, spleen, uterus, ovary or testis of the rabbit. Within 6 hours after injection a high concentration occurs in the gall bladder. Dibromestrone is not localized selectively in the uterus, ovaries or liver of the female monkey or in the uterus of the dog. It is excreted through the common bile duct into the intestine from which it may be reabsorbed into the portal circulation, finding its way eventually to the kidney and into the urine. The observations made support the theory of an enterohepatic circulation of dibromestrone and possibly of other steroids too.

The uptake of radiophosphorus in the phospholipid fraction of mouse epidermis in methylcholanthrene carcinogenesis, C. Costello, C. Carruthers, M. Kamen, R. Simoes (Depts. of Surgery and Anatomy, Barnard Free Skin and Cancer Hosp., St. Louis), *Cancer Research* **7,** 642–646 (1948). An investigation using P^{32} was made of the effect of methylcholanthrene on lipid phosphorus and on the uptake of phosphorus in the lipid fraction of mouse epidermis undergoing carcinogenesis. A drop of 30% in the lipid phosphorus content of the epidermis was caused by the carcinogen, but in the carcinoma the lipid phosphorus content was nearly twice normal. The rate of uptake in hyperplastic and in carcinoma was rapid and these tissues retained their labeled phosphorus for a considerable time.

The applications of radioactive tracer techniques to pharmacy and pharmaceutical research, J. Christian (Univ. School of Pharm., Lafayette, Ind.). *J. Am. Pharm. Assoc.* **37,** 250–253 (1948).

A brief review of some of the applications of radioactive isotopes to pharmaceutical research.

The fate of radioactive copper administered to the bovine, C. Comar, G. Davis, L. Singer (Florida Agric. Exper. Sta., Gainesville), *J. Biol. Chem.* **174,** 905–914 (1948). Only a small percentage of orally administered Cu^{64} is absorbed by bovine; the absorbed copper is found in nearly every tissue. Immediately following intravenous injection, copper rapidly disappears from plasma and is slowly accumulated by red blood cells. Accumulations of orally administered and intravenously injected copper by various tissues are presented and discussed.

Isolation of a peptide in guinea pig liver homogenate and its turnover of leucine, H. Borsook, C. Deasy, A. Haagen-Smit, G. Keighley, P. Lowy (Wm. G. Kerckhoff Lab. of the Biolog. Sci., California Inst. of Tech., Pasadena), *J. Biol. Chem.* **174,** 1041–1042 (1948). Leucine labeled with C^{14} in the carboxyl group was incubated with an amino acid mixture corresponding to casein and fumarate under oxygen. Proteins were precipitated by boiling and the presence of a radioactive fraction just before leucine was revealed by partition chromatography of the nonprotein filtrate. Hydrolysis and chromatography of this fraction revealed that all of the radioactivity was due to leucine. Leucine turnover obtained from the radioactivity of the leucine isolated from the radioactive peptide was 40% in 6 hours.

The incorporation of adenine into pentose and desoxypentose nucleic acids, G. Brown, M. Peterman, S. Furst (Sloan-Kettering Inst. for Cancer Research, New York), *J. Biol. Chem.* **174,** 1043–1044 (1948). Labeled adenine was fed to rats and the pentose nucleic acids, PNA, and the desoxypentose nucleic acids, DNA, isolated. Analyses of the adenine and guanine isolated from each fraction show that 15.9% of the adenine and 9.1% of the guanine in the PNA fraction originated from the dietary adenine. The ratio of PNA purine turnover to DNA purine turnover was 29:1. Because of uncertainties in isolation, the N^{15} take-up in the DNA fraction may have been due partially or entirely to PNA contamination. The PNA purine to DNA purine ratio of 29:1 is much higher than any of the comparable figures of phosphorus turnover suggesting that some portion of the phosphorus moieties of a nucleic acid may be exchanged without the purine of the C-N skeleton being affected.

On the conversion of palmitic acid labeled with radioactive carbon to glucose by the alloxan-diabetic rat, I. Chaikoff, S. Lerner, C. Entenman, W. Dauben (Div. of Physiol., Univ. of California Med. School, Berkeley), *J. Biol. Chem.* **174,** 1045–1046 (1948). Palmitic acid labeled in the sixth carbon was administered to alloxan-diabetic rats. $NaHC^{14}O_3$ was injected intraperitoneally into another group of alloxan-diabetic rats. Urinary glucose was isolated from both groups. Of the glucose carbon excreted by the latter group, 16% was obtained from the $NaHCO_3$. A much lower percentage of glucose carbon was obtained from the sixth carbon of palmitic acid. This suggests that some process other than CO_2 fixation was involved in the incorporation of the labeled carbon of palmitic acid into glucose.

Influence of adrenalectomy and fasting on the incorporation of isotopic nitrogen into the tissues of mice, A. White, H. Hoberman, C. Szego (Depts. of Physiolog. Chem. and Int. Med., Yale Univ., New Haven, Conn.), *J. Biol. Chem.* **174,** 1049–1050 (1948). Adrenalectomized mice were given glycine labeled with N^{15} via intraperitoneal injections. The animals were exsanguinated and selected organs and tissues were analyzed for isotopic content. The findings confirm that nitrogen catabolism is retarded following adrenalectomy.

Spontaneous and experimentally induced uptake of radioactive iodine in metastases from thyroid carcinoma: A preliminary report, S. Seidlin, E. Oshry, A. Yalow (Med. Div. and Med. Physics Res. Lab., Montefiore Hospital, New York), *J. Clin. Endocrinol.* **8,** 423–432 (1948). In 8 of 14 unselected cases of metastatic thyroid carcinoma, uptake of radioactive iodine was demonstrated. Uptake by the metastatic carcinoma showed a closer correlation to the degree of preceding thyroidectomy than to the histologic structure or "type" of tissue involved. In those cases where no initial uptake could be shown, such uptake was induced by either thyroidectomy or injections of thyrotropic hormone.

Studies with radioactive penicillin, D. Rowley, J. Miller, S. Rowlands, E. Lester-Smith (Wright-Fleming Inst. of Microbiology, St. Mary's Hospital, London), *Nature* **161,** 1009–1010 (1948).

Radioactive penicillin was prepared by incubating S^{35} with a strain of P. chrysogenum. A measured amount of radioactive penicillin was added to a suspension of Staphylococcus aureus and aliquots were removed at standard intervals for radioactive assay. The samples were filtered and the filtrate and original suspension compared for radioactivity. Any uptake of penicillin by the bacteria would be manifested by a decrease in isotope concentration in the filtrate. Results of analyses showed that this was not the case.

Cytogenetic effects in corn exposed to atomic bomb ionizing radiation at Bikini, L. Randolph, A. Longley, C. Li (Dept. of Botany, Cornell Univ., Ithaca, N. Y.), *Science* **108,** 13–15 (1948). The experiments included a comparison of the effects of the radiation of the bomb with measured doses of X-ray. Seed germinability was not affected by the radiations from the bomb or by the X-ray treatments. A comparison of other effects of radiation from the bomb and X-ray treatment is given.

The study of peripheral vascular disease with radioactive isotopes—Part I, D. Elkin, F. Cooper, Jr., R. Rohrer, W. Miller, Jr., P. Shea, Jr., E. Dennis (Whitehead Dept. of Surg., Emory Univ. School of Med., Ga.), *Surg. Gynecol. Obstet.* **87,** 1–8 (1948). Two methods involving the use of Na^{24} for the investigation of circulatory physiology of the extremities are compared and discussed. A detailed description is given of the apparatus used. The results of one of the methods used in a series of normal individuals are given.

. . . BERNARD KANNER

PHYSICAL PUBLICATIONS

Some high-frequency measurements on a cyclotron model, G. Lindstrom, *Ark. Mat., Astron. Fysik* **35,** No. 10, 1–10 (1948). To determine the characteristics of the r-f system for a proposed 90-in. cyclotron, a 1:10 model was used. The experimental method and the results are given.

On the anomalous absorption of gamma-photons, P. K. Sen Chaudhury, *Indian J. Phys.* **22,** 106–118 (1948). The apparent absorption of RaC gamma rays in lead of thicknesses from 16 cm to 20 cm, as measured with a G-M counter, was shown to vary in opposite senses with the thickness according to the distance of the counter from the surface of the lead, because of the combined effect of heterogeneity of the photon beam and the secondary radiation produced in the lead.

Shipping of radioisotopes, K. Z. Morgan (Oak Ridge Natl. Lab., Oak Ridge, Tenn.), *J. Applied Phys.* **19,** 593–598 (1948). The problem of shipping isotopes emitting gamma rays, neutrons, or beta rays is introduced historically. The new regulations for shipment by rail, motor vehicle, and air are given.

Irradiation of biological materials by high-energy Roentgen rays and cathode rays, J. G. Trump, R. J. Van de Graaff (Massachusetts Inst. of Technology, Cambridge, Mass.), *J. Applied Phys.* **19,** 599–604 (1948). An electrostatic generator was used to produce electron and X-ray streams of energy up to 4 Mev, which were directed onto samples for an investigation of their biological, photochemical, and germicidal effects. Such changes are brought about by excitation and ionization of atoms of the absorber. Sterilizing doses of radiation can be administered with a temperature rise of only 2° C.

Biological and photo-chemical effects of high energy, electrostatically produced Roentgen rays and cathode rays, C. G. Dunn, W. L. Campbell, H. Fram, A. Hutchins (Massachusetts Inst. of Technology, Cambridge, Mass.), *J. Applied Phys.* **19,** 605–616 (1948). The effects of radiations (high-energy X-rays and electrons) on microorganisms are discussed. Percentages of spore-forming and non-spore-forming bacteria destroyed by various dosages are given; 500,000 roentgens usually destroyed all non-spore-forming and 99.9% of spore-forming bacteria.

Sur l'énergie de liaison des noyaux atomique He^4 et He^5, J. Humblet (University of Liège, Liège, Belgium), *Physica* **14,** 285–293 (1948). The Ritz variational method is used to calculate the binding energies of He^4 and He^5, using the Moller-Rosenfeld mixed meson theory. The He^4 energy is found to be 23 Mev (experimentally it is found to be 28.2 Mev). He^5 is found to be unstable against neutron emission by 0.8 Mev.

On the application of Heisenberg's theory of *S*-matrix to the problems of resonance scattering and reactions in nuclear physics, N. Hu (Univ. Inst. For Teor. Fysik, Copenhagen, Denmark), *Phys. Rev.* **74,** 131–140 (1948). A general account of the Heisenberg theory is followed by a further consideration of the poles and zeros in the complex k (momentum) plane of the S-matrix. A generalized scattering formula is derived which includes resonance, antiresonance, and potential scattering, which is really resonance scattering due to quasi-stationary states determined by poles far away from the positive real k axis.

Scattering of particles by the gas in a synchrotron, N. M. Blachman (Brookhaven Natl. Lab., Upton, N. Y.), E. D. Courant (Cornell Univ., Ithaca, N. Y.), *Phys. Rev.* **74,** 140–144 (1948). The oscillations of the beam in a proton synchrotron will be increased in amplitude by the scattering (mainly elastic) of the protrons by residual gas nuclei. These oscillations, if large enough, will cause loss of some of the beam by causing it to hit the walls. A calculation is carried out to find the amplitudes of these oscillations, and the results are applied to two proposed proton synchrotrons to determine the pressure to which they must be evacuated so that no more than 10% of the beam will be lost (the values are of the order of 10^{-8} mm Hg).

The radial dependence of the tensor force in the deuteron, W. G. Guindon (Mass. Inst. of Technology, Cambridge), *Phys. Rev.* **74,** 145–149 (1948). Deuteron properties are discussed in terms of a n-p potential consisting of ordinary plus tensor forces of different well radii. Wave functions are calculated for various pairs of radii, and quadrupole moments from them. No particular pair seems to be favored, and a simple potential with equal ranges fits all data within experimental error. It is a square well of depth 13.25 Mev and radius 2.663×10^{-13} cm. $V = -(1 + S_{12})J(r)$, where V is the potential, S_{12} the spin-dependent tensor operator, and $J(r)$ the square well.

Fission excitation functions, J. Jungerman, S. C. Wright (Univ. of California, Berkeley), *Phys. Rev.* **74,** 150–152 (1948). Thorium- and uranium-coated aluminum foils were stacked with aluminum "catchers" and bombarded with alpha particles, deuterons, and protons. The beta activities of fission fragments collected on the "catchers" were measured with thin-walled cylindrical Geiger counters. The various catchers show activities in a constant ratio for different times after bombardment, indicating that the distribution of fission fragments in the complex is independent of energy in a given reaction. Fragment activity is therefore used to indicate relative number of fissions at different energies. Excitation functions are shown.

Evidence for heavy nuclei in the primary radiation, P. Freier, E. J. Lofgren, E. P. Ney, F. Oppenheimer (Univ. of Minnesota, Minneapolis), H. L. Bradt, B. Peters (Univ. of Rochester, N. Y.), *Phys. Rev.* **74,** 213–217 (1948). Balloon flights to 90,000 feet have yielded photographic plate and cloud-chamber data indicating the presence at these altitudes of heavy nuclei (Z from 15 to 40). Their mass is inferred from their very high ionization, as compared with alphas near the end of their range, and from the emission of large numbers of slow electrons emerging from their tracks. Decrease of track width may indicate filling of the electronic shells. The high energy (about ½ Bev per nucleon) is inferred from the penetration of lead plates. The rapid decrease of flux with zenith angle excludes the hypothesis that the particles are secondaries of very-high-energy protons, which are isotropic at this altitude.

On closed shells in nuclei, M. G. Mayer (Univ. of Chicago, Ill.), *Phys. Rev.* **74,** 235–239 (1948). The experimental evidence for the particular stability of nuclei with 20, 50, 82, or 126 neutrons or protons is summarized. The largest number of different nuclei with the same number of neutrons occur at 50 and 82, only one of these being active with a long-life, low-energy beta ray. The energies of radioactive decay as a function of neutron number drop sharply below 126. Evidence from delayed neutron emission, absorption cross sections, and asymmetric fission is also given.

Neutron induced radioactivity in certain rare-earth elements, J. M. Cork, R. G. Shreffler, C. M. Fowler (Univ. of Michigan, Ann Arbor), *Phys. Rev.* **74,** 240–243 (1948). Half-lives and the beta and gamma energies of specimens of lanthanum, neodymium, samarium, europium, gadolinium, and terbium heavily bombarded in a pile were determined by absorption and spectrometric methods. Probable mass numbers are assigned to the active isotopes.

The isotopes Os^{185} and Os^{193}, L. I. Katzin, M. Pobereskin (Argonne Natl. Lab., Chicago, Ill.), *Phys. Rev.* **74,** 264–267 (1948). Osmium bombarded with neutrons in a pile was chemically treated, and activity measurements were made with end-window Geiger counters. Os^{193}, with a 15.0 day half-life, emits a beta of energy no more than 0.165 Mev, and simultaneously a highly converted gamma ray of 0.13 Mev. Os^{185} emits a gamma ray of 0.75-Mev energy with each K-capture, following a 97-day half-life.

The radioactive decay constants of K^{40} as determined from the accumulation of Ca^{40} in ancient minerals, L. H. Ahrens, R. D. Evans (Massachusetts Inst. of Technology, Cambridge), *Phys. Rev.* **74,** 279–286 (1948). The probability of K^{40} decay by electron capture and electron emission are computed using the Ca^{40}/K^{40} ratio in very old minerals. That for electron capture is found to be 0.9×10^{-9} yr^{-1}, for beta-decay 0.65×10^{-9} yr^{-1}, giving a total half-life of 0.45×10^{9} yr for K^{40}. Of K^{40} disintegrations, 42% are by beta emission to the ground state of Ca^{40}, 4% by electron capture to a 1.5-Mev excited state in A^{40}, and 54% by electron capture to the ground state of A^{40}.

The disintegration of scandium^{46}, gold^{198}, and tungsten^{185,187}, C. L. Peacock, R. G. Wilkinson (Indiana Univ., Bloomington), *Phys. Rev.* **74,** 297–303 (1948). Samples produced by neutron and deuteron bombardment were investigated in a semicircular spectrometer. Sc of 85-day half-life emits two β ray groups. Au^{198} emits a single group of β rays, the residual nucleus emitting a γ ray. Two β groups and five γ rays are emitted by 24-hour W^{187}; one β group by 77-day W^{185}.

Use of an electron multiplier tube as a new technique in disintegration experiments, L. del Rosario (Univ. of Chicago, Chicago, Ill.), *Phys. Rev.* **74,** 304–314 (1948). The disintegration products from the reactions $Be^{9}(p,\alpha)Li^{6}$ and $Be^{9}(p,d)Be^{8}$ were electrostatically analyzed to measure their energies and detected by an electron multiplier tube with 12 electrodes. Bombarding energies of 239, 268, and 397 kv were obtained from a voltage quadrupling circuit. The energy release in the two reactions are 2.074 ± 0.03 and 0.541 ± 0.003 Mev, respectively. The lack of windows provides a considerable advantage in the use of the multiplier as a detector.

Gamma-ray spectrometer measurements of fluorine and lithium under proton bombardment, R. L. Walker, B. D. McDaniel (Cornell Univ., Ithaca, N. Y.), *Phys. Rev.* **74,** 315–327 (1948). A gamma-ray spectrometer is described which measures the gamma-ray energy by magnetic analysis of electron-positron pairs which they produce in a thin radiator. Coincidences among spaced counters determine the sum of the radii of curvature of the positron and electron. The resolution is about 5% (half-width in energy) for a sufficiently high energy (over 5 Mev); the factors limiting the resolution are discussed. Lines were found at 14.8 Mev and 17.6 Mev from the excited state produced by bombardment of lithium. The radiation from fluorine was found to consist of lines at 6.13 and 6.98 Mev.

The resonance scattering of slow neutrons in crystals, R. Sternheimer (Univ. of Chicago, Ill.), *Phys. Rev.* **74,** 335–340 (1948). The diffraction pattern for a single ideal crystal on which a beam of neutrons is incident is calculated for the case in which the neutron energy lies in the region of a resonance, using the method of the pseudopotential. The Laue-Bragg scattering and isotropic background are derived.

Production of neutrons by the capture of cosmic-ray mesons at sea level, G. Groetzinger, G. W. McClure (Univ. of Chicago, Ill.), *Phys. Rev.* **74,** 341–342 (1948). An attempt was made to obtain information concerning the capture of mesons at sea level by searching for neutrons emitted in the process. A circuit was used giving coincidences representing the stoppage of a meson in a lead block plus the production, and detection in BF_3 counters, of a neutron. Four out of 1,167 negative mesons stopped gave neutron counter pulses with delays of 1–10 microseconds; none of 688 positive mesons gave neutrons. Consideration of neutron counter efficiency and time required to slow the neutrons in paraffin indicate approximately two neutrons produced per negative meson captured in lead.

Some observations concerning the energy of nuclei, E. Glueckauf (Atomic Energy Research Establishment, Harwell, Didcot, England), *Proc. Phys. Soc.* **61,** 25–33 (1948). The binding energy of α particles as a function of the number of protons and neutrons shows sharp fluctuations, at fairly regular intervals, possibly due to discontinuous changes in nuclear

radius and density. Irregularities of the β stability line and the mass-defect curve must occur in the same region. Data on energy of β decay show that nuclei of odd mass number have about 0.2 Mev higher binding energy for even than for odd proton number.

The temperature effect on cosmic-ray intensity and the height of meson formation, A. Duperier (Univ. of Manchester, England), *Proc. Phys. Soc.* **61,** 34–40 (1948). The large discrepancies between various observers' values for the ground-temperature coefficient of cosmic-ray intensity as well as the seasonal variation of the coefficient may be taken as evidence for the decay of the meson. The annual variation may be accounted for by the assumption that most mesons originate at the 7.5 cm Hg level of the atmosphere.

The design of linear accelerators, J. C. Slater (Massachusetts Inst. of Technology, Cambridge), *Revs. Mod. Phys.* **20,** 473–518 (1948). Following a discussion comparing the linear accelerator to other electron and positive-ion accelerating machines, a complete treatment is given of the properties of periodically loaded wave guides, power input, and coupling of oscillators to the guide are described, with particular attention devoted to long accelerators. The behavior of particles in the wave guide is calculated, and electron dynamics applied to different types of accelerators under construction or consideration. A treatment of the transverse motion and of focusing problems is included.

Interpretation of cosmic-ray phenomena, B. Rossi (Massachusetts Inst. of Technology, Cambridge), *Revs. Mod. Phys.* **20,** 537–583 (1948). The fundamental experiments on cosmic-rays are described and summarized, and an attempt made to fit their results into an over-all picture of cosmic-ray phenomena. The hard and soft components and their variation with altitude, the momentum spectrum of mesons, cosmic-ray transformations, stars, and participation of nucleons in cosmic-ray events are discussed. The primary radiation is concluded to consist of positively charged particles other than electrons and ordinary mesons, which interact strongly with atomic nuclei. A phenomenological approach is made to the explanation of high and low-energy nuclear events, the analysis of the hard and soft components and of the meson and electron components. An estimate is made of the total energy entering the earth's atmosphere in the form of cosmic rays (695-Mev cm^{-2} sec^{-1} $sterad^{-1}$).

Coincidence-counting system of high resolution, H. L. Schultz, R. Beringer (Yale Univ., New Haven, Conn.), *Rev. Sci. Instr.* **19,** 424–427 (1948). A circuit is described which gives small uncertainty time between the counting event and its registration. Two channels of counters and amplifiers produce artificial pulses separated by an arbitrary delay, going to a phase detector which measures the degree of overlap. Using a collimated beam of alpha particles, the width of the coincidence-rate vs. time-delay curve was about 3×10^{-8} sec. For beta-rays it was 5×10^{-7} sec.

A proton-controlled magnetic field regulator, M. E. Packard (Stanford Univ., Stanford, Cal.), *Rev. Sci. Instr.* **19,** 435–439 (1948). The nuclear induction signal from protons is used to give a large change in d-c voltage for a small change in magnetic field. Using the magnetic field discriminator, a degenerative current regulator controls the magnetic field to 0.02 gauss for a 10% variation in line voltage.

A mass spectrometer magnet, H. S. Anker (Univ. of Chicago, Ill.), *Rev. Sci. Instr.* **19,** 440–441 (1948). A magnet is described which uses ring-shaped pole pieces and an internal core, making possible a weight of 165 lb, including the coil, for a mass spectrometer using a 15-cm radius.

The detection of beta-radiation by photographic film, J. Cobb, A. K. Solomon (Harvard Med. School, Boston, Mass.), *Rev. Sci. Instr.* **19,** 441–447 (1948). Nineteen types of film were exposed to the β radiation from C^{14} in various intensities. Background, sensitivity, contrast, and granularity were measured in each case. Eastman No-Screen X-ray film was judged from these results to be best for the detection of β-rays, and Eastman Type M X-ray stripping film best for radioautography.

Dead-time reduction in self-quenching counters, P. B. Smith, *Rev. Sci. Instr.* **19,** 453–457 (1948). Methods of reducing dead time are discussed, including collection of ions by application of a

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negative pulse to the counter wire and operation at high gain. The first method reduces the dead time from 160 to 80 microseconds in the most favorable case. Operation just below threshold also reduces dead time to approximately zero, counting beta particles with an efficiency of 50–70%. High gain without a negative pulse also reduces the dead time by a factor of two.

A method for measuring short period activities, A. D. Schelberg, M. B. Sampson, A. C. G. Mitchell (Indiana Univ., Bloomington), *Rev. Sci. Instr.* **19,** 458–461 (1948). Using a pneumatic tube, a sample was transferred from bombarding to counting position in 0.2 sec. The pulses from a thin-walled aluminum Geiger counter were fed into the x-axis amplifier of an oscillograph without sweep, and recorded on a moving film. By inspecting the film and using the correction for counter dead time, the counting rate as a function of time was determined. The decay curve gave the half-life of the activity. A^{35} produced by alpha particle bombardment of sulfur (emitting a neutron) had a 1.84-sec half-life. Cl^{32} had a 2.8-sec half-life, and that of Ti^{43} had a 0.58 sec half-life.

The use of retarding potentials with the mass spectrometer, R. E. Fox, J. A. Hipple (Westinghouse Research Labs., East Pittsburgh, Pa.), *Rev. Sci. Instr.* **19,** 462–466 (1948). By use of retarding potentials, the smearing of the ion beam at high pressures may be eliminated by rejection of ions that have lost energy. Ions formed with kinetic energy may also be studied.

Multiple Geiger counters for the observation of particle tracks, W. H. Chambers (Cornell Univ., Ithaca, N. Y.), *Rev. Sci. Instr.* **19,** 467–470 (1948). A chamber containing an array of 16 self-quenching Geiger counters made of a central wire surrounded by eight copper wires was used with its recording circuit to determine the tracks of alpha and beta particles. The use of a common atmosphere does away with scattering in windows and eliminates corrections such as are necessary with an array of thin-walled counters. Spurious counts occur in counters adjacent to the track because of photons incompletely absorbed by the quenching gas, at the rate of about 1.5% of the tracks.

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